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THE RADIATION OF SOUND

by TH. van URK and R. VERMEULEN.

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The radiation of sound is investigated for the simplest forms of radiating body. In the first place the differential equations are set up for a spherically symmetrical air movement, such as can be obtained by means of a pulsating sphere. The solutions of the differential equations are discussed and a mechanical model is deduced which causes by its movement the same reaction on the driving centre as the air on the pulsating sphere. By means of the model the different forms of air movement are treated, particularly sinusoidal movement with different frequencies. In practical cases the pulsating sphere may be regarded as an idealized case of a loud speaker with a large baffle board. A loud speaker without a baffle must be idealized as an oscillating rigid sphere. For this case also a mechanical model is described, by means of which the behaviour of the radiator at various frequencies may be demonstrated. Finally the radiation properties of the pulsating sphere and of the oscillating sphere are compared.

Introduction

Sound is a movement of the air which is perceptible to the ear. This definition, although it is useful and correct, is not entirely satisfactory. It does not express the fact that it is especially the fluctuations of the air pressure which accompany its motion which stimulate the ear. Moreover, the hearer is not aware of sound as a property of the air surrounding him, but as the presence of a source of sound at a certain distance away. In this article we shall study how the fluctuations in pressure are created at the spot where the listener is situated by the source of sound *via* the motion of the air. It will be found that the motion of a body is in itself insufficient to cause the air to move at great distances so that we can perceive the movement as sound. Only rapid changes of the motion of a body cause disturbances in the air which are propagated with comparatively little attenuation in all directions from the source: sound waves. The same phenomenon is indeed also encountered in electrotechnology: the field of a charged condenser or of a magnet can only be observed at short distances, by induction for example. On the other hand, upon rapid changes of charge and current radio waves occur which make possible communication over great distances. By analogy with the radiation of light waves one speaks of the radiation of radio

waves by an aerial and of the radiation of sound waves by a source of sound.

From time immemorial the builders of musical instruments have sought intuitively and empirically the shape which renders a body a good sound radiator. In our times the problem has taken on new significance in the construction of loud speakers. In this case the problem takes on a simpler form because the radiator here does not and even must not perform the function of determining the timbre.

The essence of the problem is now to determine how much energy is radiated in the form of sound with different shapes and types of motion of the radiator. For the very simplest forms the answer will be elucidated with the help of mechanical models.

The pulsating sphere

The first radiator for which we shall derive a model is the "pulsating sphere", *i.e.* a sphere whose radius increases and decreases with the time. One may imagine a rubber balloon which is more or less blown up. The motion of the air around the sphere (see *fig. 1*) will, like the motion of the sphere itself, take place only in radial directions, and will have the same velocity (v) in all directions, but it will

depend upon the distance from the centre of the sphere (r). We shall now set up the differential equations for this spherically symmetrical motion of the air and discuss their solution.

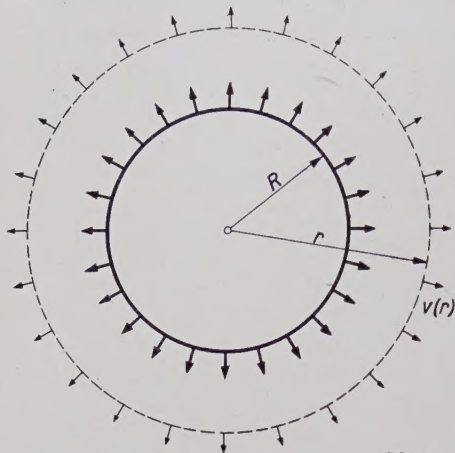


Fig. 1. Pulsating sphere. In the expansion of the sphere (radius R) a spherically symmetrical motion of the air takes place with the velocity v at the distance r .

If we consider the layer of air between two spheres with radii r and $r + dr$, this layer will, after a short time dt , have been displaced as a whole over a distance $v \cdot dt$. But in the case where there is a velocity gradient $\partial v/\partial r$, the outer sphere will have moved with the velocity $v + (\partial v/\partial r)dr$, and thus the thickness of the layer of air will have been increased to $dr + (\partial v/\partial r)dr \cdot dt$. The volume of the layer, which was originally $4 \pi r^2 dr$, will after a time dt therefore be enlarged for two reasons: firstly because the radius has increased by $v dt$, and secondly because the thickness has increased by $(\partial v/\partial r)dr \cdot dt$. The relative increase dV of the volume V therefore amounts to:

$$\frac{dV}{V} = 2 \frac{v}{r} dt + \frac{\partial v}{\partial r} dt \dots \dots (1)$$

The enlargement of the volume results in a decrease in the pressure, since the amount of air enclosed remains the same. If the exchange of heat with the environment is neglected, thus if the expansion takes place adiabatically, the relation between pressure and volume is given by the well known law: $p \cdot V^\gamma = \text{constant}$, from which the change of pressure dp follows:

$$\frac{dp}{B} = -\gamma \cdot \frac{dV}{V}, \dots \dots (2)$$

where B represents the average air pressure, i.e. the barometric pressure. From the combination of formulae (1) and (2) the velocity at which the pres-

sure increases in the air flow is found:

$$\frac{\partial p}{\partial t} = -\gamma B \cdot \frac{dV}{V dt} = -\gamma B \left(2 \frac{v}{r} + \frac{\partial v}{\partial r} \right) \dots (3)$$

In addition to this "continuity equation" a second equation may be written which expresses the fact that a change in the velocity of the air occurs in a radial direction when there is a pressure gradient. In order to calculate this we cut out of the spherical layer of air dr in thickness, a small cylinder with a cross section dO and a height dr (see fig. 2). The pressure on the curved surface of this cylinder will produce no acceleration, but the pressure $(\partial p/\partial r)dr$ on the top surface will be greater than that on the lower surface. The retarding force $(\partial p/\partial r)dr \cdot dO$ acts on the mass $\varrho \cdot dr \cdot dO$ (where ϱ is the density of the air), so that

$$-\frac{\partial p}{\partial r} \cdot dr \cdot dO = \varrho \cdot dr \cdot dO \cdot \frac{dv}{dt},$$

$$\frac{\partial p}{\partial r} = -\varrho \frac{dv}{dt} \dots \dots (4)$$

In order to find a solution of equations (3) and (4), an auxiliary quantity Ψ may well be introduced by means of the relations:

$$p = \varrho \frac{\partial \Psi}{\partial t} \dots \dots (5)$$

$$v = -\frac{\partial \Psi}{\partial r} \dots \dots (6)$$

The problem is hereby reduced to the determination of a single function Ψ :

From (5) it follows directly that

$$\frac{\partial p}{\partial r} = \varrho \frac{\partial^2 \Psi}{\partial r \partial t}$$

and from (6)

$$\frac{\partial v}{\partial t} = -\frac{\partial^2 \Psi}{\partial r \partial t},$$

so that equation (4) is satisfied with an arbitrary function Ψ .

From equation (3), however, another condition

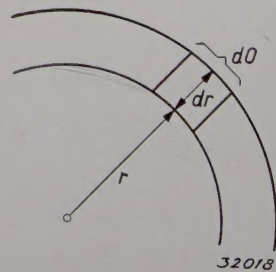


Fig. 2. The element of volume which is considered for the derivation of equation (4).

for Ψ can be derived. By substituting (5) and (6) in (3) the following differential equation is found:

$$\frac{\partial^2}{\partial t^2} (r \Psi) = \frac{\gamma B}{\rho} \frac{\partial^2}{\partial r^2} (r \Psi).$$

This is the well known wave equation for the quantity $(r \Psi)$. The general solution is:

$$\Psi = \frac{1}{r} [F(r - \sqrt{\gamma B/\rho} t) + G(r + \sqrt{\gamma B/\rho} t)], \quad (7)$$

where F and G are arbitrary functions.

From the fact that the time occurs only in the combination $(r - \sqrt{\gamma B/\rho} t)$ in equation (7) it may clearly be seen that the character of this term is that of a wave directed outwards, of otherwise arbitrary form and intensity. This combination retains the same value when r increases with the velocity

$$c = \sqrt{\gamma B/\rho} \quad \dots \quad (8)$$

This is therefore the velocity of propagation of the travelling wave.

As an example we shall work out the case of a purely sinusoidal wave directed outwards. In this case we are concerned only with F , and this F must be a harmonic function of $r - ct$, so that Ψ may for instance be written in the form

$$\Psi = \frac{A}{r} \sin \frac{\omega}{c} (ct - r) = \frac{A}{r} \sin (\omega t - kr), \quad (9)$$

where A is an arbitrary constant and $k = \omega/c$. k is actually the number of waves over the length 2π .

With the help of (5) and (6) the pressure and velocity in the sound wave may be derived from Ψ given by equation (9). One obtains:

$$p = \rho \frac{A}{r} \omega \cos (\omega t - kr) \quad \dots \quad (10)$$

$$v = k \frac{A}{r} \left[\cos (\omega t - kr) + \frac{1}{kr} \sin (\omega t - kr) \right]. \quad (11)$$

The spherical wave described in this way may be excited by means of the afore-mentioned pulsating sphere. The velocity v of the pulsating surface is found by substituting the radius R of the sphere for r in equation (11). In the same way equation (10) gives the pressure on the surface of the sphere, and hence the force of reaction $4\pi R^2 \cdot p(R)$ of the sound field on the radiator.

It may be seen from the equations that the velocity and reaction force are proportional to each other and shifted in phase to a certain amount. The relation between force and velocity therefore corresponds in character to the relation between

voltage and current in electrical circuits, and it is reasonable to represent mathematically the relation of force to velocity, by analogy with the relation of voltage and current, by a complex impedance of the radiator. This impedance Z can be calculated by dividing force and velocity at the surface of the sphere by each other (both must be written in the complex form $e^{j(\omega t - kr)}$):

$$\frac{1}{Z} = \frac{v(R)}{4\pi R^2 p(R)} = \frac{1}{4\pi R^2} \left(\frac{1}{\rho c} + \frac{1}{j\omega \rho R} \right). \quad (12)$$

Besides being concerned with the impedance of a radiator, we are primarily concerned with the energy dissipated. This can be calculated as the product of the velocity of the surface of the sphere and the force of reaction, or — as in electrotechnology — as the square of the maximum velocity multiplied by the real part of the impedance. The fact that the impedance also possesses an imaginary component means that there is, in addition to the energy radiated, also wattless energy, *i.e.* energy which passes back and forth periodically between the radiator and the field of sound.

In order to be able to understand the physical significance of the actual and the "wattless" power in the sound field, and to obtain in addition an idea of the behaviour of the radiator at different frequencies and with other forms of motion than the sinusoidal one, a mechanical model will be introduced which possesses the same impedance as is indicated in formula (12) for the reaction of the air (*fig. 3*). This model consists of a mass M which is driven at point A via a mechanical resistance, represented by an oil cylinder with a perforated piston. The piston can be moved with respect to the cylinder, and due to the viscosity of the oil it experiences a resistance proportional to its velocity. By this frictional resistance a force K is applied to the mass, proportional to the difference in velocity between piston and cylinder, or between the driving centre A and the mass M which amounts to the same thing. If the driving centre has the velocity v_0 and the mass the velocity v_2 , the re-

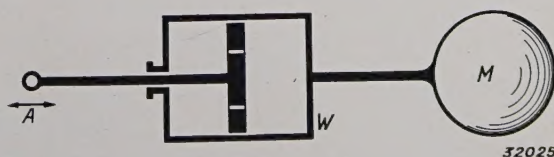


Fig. 3. Mechanical model consisting of a mass and a frictional resistance which upon motion exerts on the driving centre A the same reaction as a compressible medium (air) on the wall of a pulsating sphere. The energy dissipated in the resistance corresponds to the energy which is radiated in the form of sound. The kinetic energy of the mass is analogous to the (wattless) energy which is taken up in the flow of air.

lative velocity of piston and cylinder $v_1 = v_0 - v_2$, and a force is exerted by the mechanical resistance:

$$K = W v_1,$$

where W is the proportionality factor between velocity and friction. This force causes the acceleration of the mass:

$$K = M \frac{dv_2}{dt}.$$

The mechanical impedance is again defined as the complex relation between the force K and the velocity v_0 of the driving centre A for sinusoidal motions:

$$\frac{1}{Z} = \frac{v_0}{K} = \frac{v_1 + v_2}{K} = \frac{1}{W} + \frac{1}{j\omega M}. \quad (13)$$

This expression has the same form as formula (12), and even becomes identical with it when the following substitutions are made:

$$\left. \begin{aligned} W &= 4\pi R^2 \cdot \varrho c \\ M &= 4\pi R^3 \cdot \varrho \end{aligned} \right\} \dots \dots (14)$$

The values found for W and M are independent of the frequency. This means that at any given frequency of the force on point A the reaction of the model is the same as the reaction of the air on the sphere. This also must hold with a force containing components with different frequencies, in other words, with a non-sinusoidal variation of the driving force.

It may be seen that in the model there are two elements which can take up the energy supplied at the driving centre A : the mass M which can retain the energy temporarily in the form of kinetic energy, and the resistance W which dissipates part of the energy¹⁾. In what form can we rediscover this energy in the air surrounding the radiator? In order to answer this question the motion of the air will again be considered on the basis of the model, making use of the fact, that the model is also valid for motions other than sinusoidal.

Application of the model

Stationary motion

When in the model the mass M and the driving

centre A move with the same constant velocity, the mechanical resistance W is apparently inactive and no force is transferred to the mass. Actually this corresponds to a stationary flow in the air, where the velocity is constant at every point, i.e. independent of time. The pressure will then also be constant at all points, and equal to the barometric pressure B . The same amount of air must flow through every spherical shell of radius r , thus: $v = v_0 R^2/r^2$, where v_0 is the velocity at R . A volume element dV will then possess a kinetic energy $dT = \frac{1}{2} \varrho \cdot dV \cdot v^2$, so that the total kinetic energy of the air flow, calculated by integrating over space, becomes:

$$T = \int_R^\infty \frac{1}{2} \varrho \cdot v_0^2 \frac{R^4}{r^4} \cdot 4\pi r^2 dr = \frac{1}{2} 4\pi R^3 \varrho v_0^2.$$

This is apparently the same expression as that found for the kinetic energy of the mass in the model, when the latter moves with the velocity v_0 . This mass therefore represents the inertia of the air flow in the air surrounding the sphere.

Motion with constant acceleration

If in the model a constant acceleration is applied at point A , the mass M will also be constantly accelerated, and the necessary constant force $K = M dv_2/dt$ must be transmitted by the resistance W . The relative velocity v_1 of the piston with respect to the cylinder will then be constant, namely

$$v_1 = \frac{M}{W} \frac{dv_2}{dt},$$

so that the acceleration of M and A also will have the same value dv_2/dt which we shall call a in the following.

It is striking that, as long as the motion is constantly accelerated, the velocity of the driving centre exceeds the velocity of the mass M by a constant amount v_1 , and the increase of the kinetic energy of M needs must be accompanied with a loss of energy in the resistance which per unit of time amounts to

$$K \cdot v_1 = W \cdot v_1^2 = \frac{M^2}{W} a^2 = 4\pi R^4 \frac{\varrho}{c} a^2.$$

To what does this correspond in reality? A constantly accelerated motion of the air at the surface of the sphere of radius R can be realized by giving the surface of the sphere a suitable acceleration. The surrounding air will then also be accelerated and the total kinetic energy of this air becomes

¹⁾ It may be noted here that in the usual manner of representation the impedance Z is divided into $Z = W' + j\omega M'$, where W' and M' are interpreted as the "radiation resistance" and the "mass in resonance" of the air. It is indeed possible to choose a resistance W' and a mass M' in such a way that the whole system exhibits the impedance Z when driven with a given frequency. The quantities W' and M' are, however, very dependent on the frequency in that case. This "model" is therefore less suitable for obtaining an objective picture of the radiation.

equal to $\frac{1}{2} M v_2^2$, just as with stationary flow. What conception must we have of the "frictional loss" $W v_1^2$? We have considered the air as a medium without friction, which therefore satisfies the law of the conservation of energy, and it is very remarkable that the behaviour of this medium can be described by means of a model in which energy losses occur.

The explanation of this apparent paradox lies in the fact that the sound field is infinite. It is found, namely, that the energy can be stored in the sound field in two different ways. Part of the energy remains concentrated in the neighbourhood of the radiator in the form of kinetic energy. This part of the sound field remains in contact with the radiator, and the energy which it takes up may be considered as wattless energy, because the sound field is capable of giving back this energy when the stream of air is no longer accelerated by the sphere, but retarded. This agrees with the fact that this kinetic energy in the case of the stationary flow corresponds to the energy of the mass M in the model which also takes up a wattless energy. Another part of the energy will, however, flow off to infinity with the excited sound wave. This energy will never be given back to the radiator and can therefore be considered as lost as far as its reaction on the radiator is concerned, even though it always remains within the infinite sound field.

In order to show that the sound wave actually does dissipate energy we shall calculate the pressure and velocity in the sound field from equation (7), assuming a wave of arbitrary shape, which is directed outward ($G = 0$). Then with the help of equations (5), (6) and (8) one finds

$$p = -\frac{\rho c}{r} \frac{\partial F}{\partial r}, \quad \dots \dots \dots (15)$$

$$v = -\frac{1}{r} \frac{\partial F}{\partial r} + \frac{1}{r^2} F. \quad \dots \dots \dots (16)$$

From these expressions may be calculated the power dissipated through a spherical shell with radius r :

$$N = 4 \pi r^2 p \cdot v = 4 \pi \rho c \left[\left(\frac{\partial F}{\partial r} \right)^2 - \frac{1}{r} F \frac{\partial F}{\partial r} \right]. \quad (17)$$

The quantities F and $\partial F / \partial r$ vary in the same way as functions of the time at all distances r from the source of sound, only with a constant displacement. From this it follows that the first term of equation (17) represents a current of energy which flows

toward infinity with unaltered intensity. The second term is an additional current of energy which dies out at great distances, which means that the corresponding energy is stored up in the neighbourhood of the radiator.

It is enlightening to consider the two parts of the sound field in the case of a very simple wave train such as occurs, when the constant acceleration of the air at $r = R$ is continued for a certain time τ , and the system is then left to itself. Fig. 4 gives the distribution of velocity in the sound wave at a number of different moments. The velocity v may be considered as the sum of two velocities $v_1 + v_2$, which were introduced in the discussion of the mechanical model. The velocity v_2 is the velocity of the "mass" M ; during the period of acceleration it is equal, at $r = R$, to $a \cdot t$, and after the conclusion of the period of acceleration it remains equal to $a \cdot \tau$. The velocity v_1 is the extra velocity which the air must have at $r = R$ in order to cause the excess pressure necessary to accelerate the air. This velocity is therefore present from the time $t = 0$ and disappears at the moment when the acceleration stops. In the model the acceleration is caused by the force of friction $W v_1 = Ma$; the extra velocity is therefore $v_1 = Ma/W$.

The model only makes it possible to determine the pressure and velocity at the surface of the sphere $r = R$. The distribution of the velocity in space is sketched in fig. 4 on the basis of the consideration that the wave which occurs upon acceleration decreases in amplitude during propagation by $1/r$, while the velocity of the stationary flow succeeding the wave decreases by $1/r^2$.

The propagation of a spherical wave is well illustrated by the phenomena taking place in an explosion. The compression which occurs here due to the sudden liberation of a quantity of gas leads to a pressure wave which we know as the detonation. This excess pressure, however, is maintained only as long as the combustion generates gas in increasing amounts. When the development of gas is at a maximum the pressure will again be normal, but high velocities, away from the centre of explosion, will occur in its neighbourhood. With decreasing gas development a lowered pressure occurs due to the inertia of the surrounding gas. This lowered pressure travels as it were as a negative wave behind the first positive wave and brings the medium to rest again. It is usually impossible to distinguish this second wave by ear since it follows the first one too closely. Its presence, however, is proved by the well known fact that the glass of the windows which are broken in houses near the centre of an explosion does not fall into the rooms, but outward on to the street. The first wave breaks the glass and the second negative wave draws the fragments outward. This succession of positive and negative forces which act on the mass M upon rapid displacement of point A can be well visualized by means of the model.

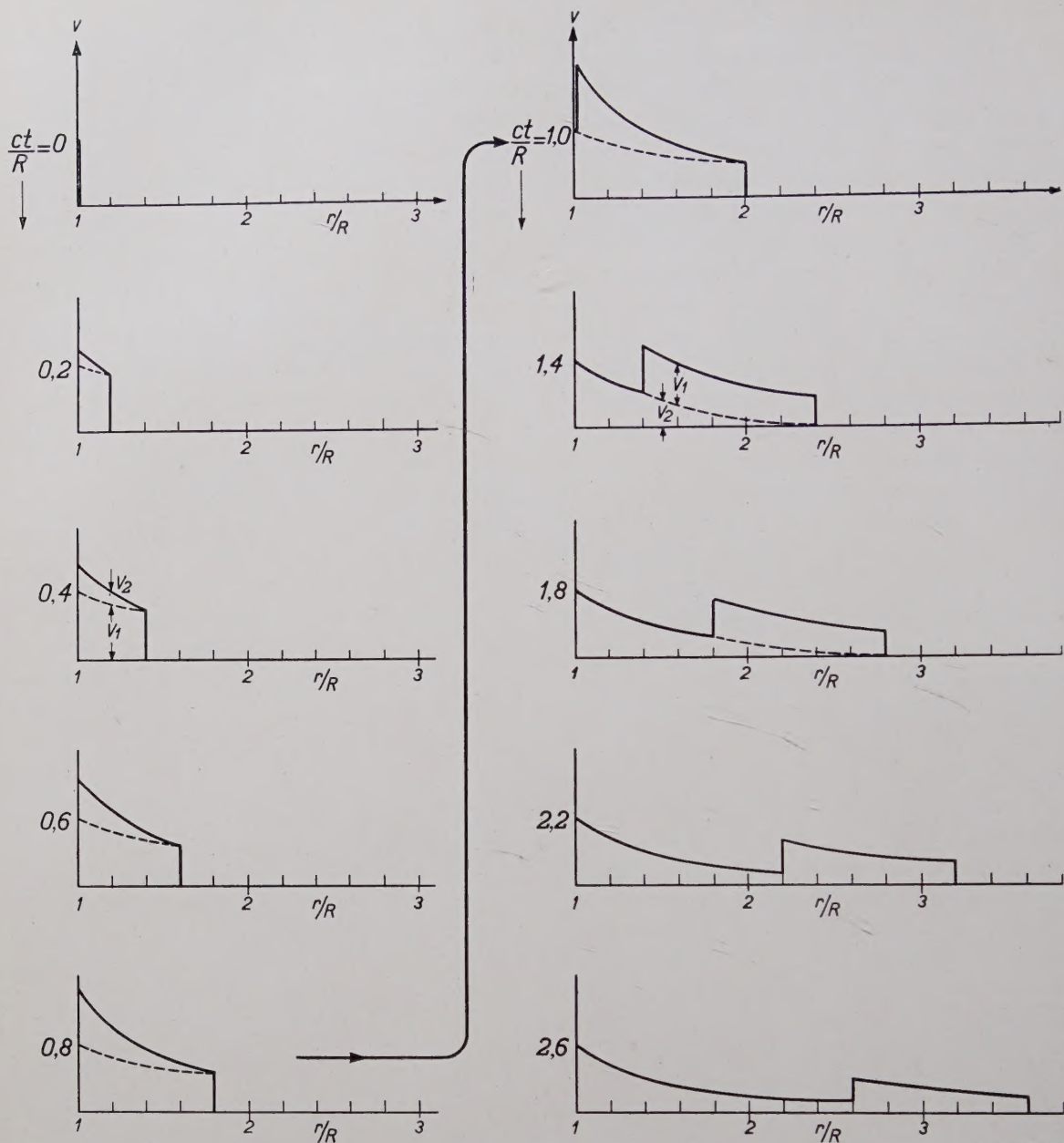


Fig. 4. The distribution of the velocity $v(r)$ in a medium at a number of successive moments upon the occurrence of a spherically symmetrical sound wave. The radius R of the sphere is chosen as unit of the distance r ; as unit of the time, the time is chosen during which the wave covers the distance $r = R$. It is assumed that an acceleration $a = 1$ is given to the air at $r = R$ during the time $t = R/c$. This means that during this time the wall of the sphere has first a velocity $v_1(R)$ which causes the compression, and thereby the increase in air pressure. By the acceleration a current of air with a velocity v_2 is built up. The total velocity v is composed from v_1 (the dotted curves in the left part) and v_2 (drawn above the dotted curves). The distribution of velocity $v_2(r)$, at the moment $t = \tau$ remains after the conclusion of the acceleration (disappearance of $v_1(R)$), the region with high pressure, however, in which the velocity $v_1(r)$ is present, now passes off to infinity as a sound wave.

Sinusoidal motions with different frequencies

Let us now consider a sinusoidal motion of the driving centre A of the model. At low frequencies the forces of inertia of the mass M will be small, so that small relative motions of piston and cylinder are enough to produce these forces, and the energy loss in the piston is small. This means that the pul-

sating sphere is in this case a poor radiator: the mass of the surrounding air gives way too easily for a strong sound wave to occur. At very high frequencies, on the other hand, the mass M will remain almost entirely at rest; the motion of the driving centre is practically all taken up by the resistance. In this case therefore the sphere will not only radiate well, but the energy given off will be independent of the

frequency at a given velocity amplitude of the surface of the sphere. The influence of the size of the radiating sphere can also be judged in this qualitative consideration. According to formula (14) the ratio of the mass M to the resistance W will become greater with a larger sphere. The radiation therefore improves. With a very great radius of the sphere, *i.e.* when practically plane waves are generated, the very great mass M remains entirely at rest, the radiation impedance becomes a pure resistance with the value ρc per unit of surface, *i.e.* the so-called wave resistance of the medium.

For frequencies lying between the two extremes formula (12) for the impedance must be employed. The real part, which determines the power radiated at a given velocity v_0 of the wall of the sphere, becomes:

$$Z_r = 4 \pi R^2 \rho c \frac{(kR)^2}{1 + (kR)^2}.$$

The imaginary part, which determines the "wattless" power, is

$$Z_i = 4 \pi R^2 \rho c \frac{(kR)}{1 + (kR)^2}.$$

The frequency occurs only in the form $kR = R\omega/c = 2\pi R/\lambda$, *i.e.* the radiation properties depend only upon the ratio of the circumference and the wave length²⁾.

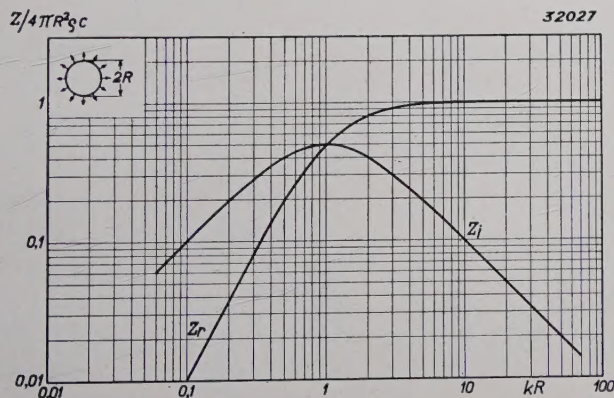


Fig. 5. Real part Z_r and imaginary part Z_i of the mechanical impedance of the air in the case of a pulsating sphere, as a function of kR . At a definite size of the sphere the abscissa therefore represents a frequency scale: one may, however, also assume that the radius R of the sphere is plotted on the abscissa for a definite frequency.

In fig. 5 Z_r and Z_i are drawn as functions of (kR) . It may be seen that at low frequencies Z_i is the dominating component, so that the impedance

possesses the character of a mass in the main, while at high frequencies Z_r becomes dominant.

If we consider particularly Z_r , the acoustic energy dissipated, we ascertain that it is independent of the frequency at high frequencies ($kR > \pi$), at lower frequencies, however, it decreases with the square of the frequency. Therefore in order to obtain satisfactory sound radiation at low frequencies, kR must be made large, *i.e.* a sphere of large radius must be used.

Practical significance of the pulsating sphere

Until now we have been concerned exclusively with the pulsating sphere. Such a radiator, called of the zero order, all points of whose surface move in the same phase, *i.e.* move simultaneously inward and outward, can scarcely be realized technically.

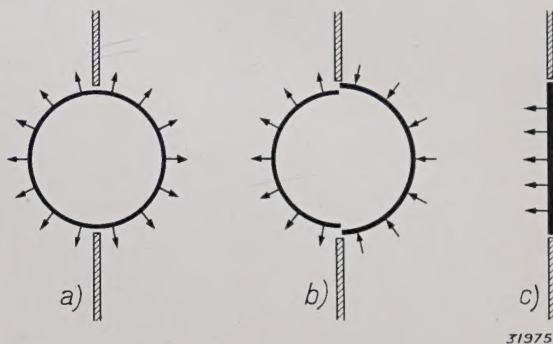


Fig. 6. The pulsating sphere is the idealized form of a loud speaker in a baffle board.

- The space around the sphere is divided into two halves by a baffle board.
- No essential change is introduced in each half of space when the phase of the motion of one half of the sphere is reversed.
- If the spherical boundary of the radiator is now replaced by a plane one, one arrives at the case dealt with by Rayleigh of an oscillating flat disc in a baffle board.

However, since the velocity in the case of the sphere is in a radial direction at all points, it makes no difference when space is divided into two parts by a solid wall through the centre of the sphere (fig. 6a), and since the two parts of space are entirely independent of each other, the conditions in each half of space will remain entirely unaltered when we reverse the phase of the motion of one half of the sphere (fig. 6b). The situation now begins to resemble that of a loud speaker membrane in an infinitely large baffle board. The sphere ought to be replaced by the cone which is usual in loud speakers, but then it is impossible to carry out the necessary calculations. The calculations can, however, be carried through for the case of a flat disc, moving back and forth in the opening of the baffle board, fig. 6c. The radiation impedances calculated by Rayleigh for this case are re-

²⁾ This fact has also been emphasized in this periodical in the discussion of the directional effect of loud speakers, see J. de Boer, Philips techn. Rev. 3, 225, 1938 and 4, 144, 1939.

presented in *fig. 7*. Oscillations are found to occur in the curves of the impedances which may be ascribed to the fact that the sound field is no longer spherically symmetrical, and interferences occur at certain wave lengths. Apart from these discrepancies, however, the general variation of the impedances is the same for the pulsating sphere and the plane disc in the baffle board, and this fact makes it reasonable to assume that for other forms of radiators of the zero order also (a cone in a baffle board, for instance) the character of the radiation impedances will be similar.

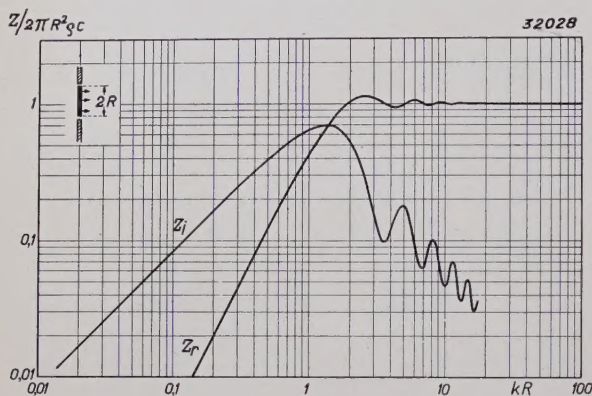


Fig. 7. Real and imaginary part of the impedance of the air upon being set in motion by the oscillating disc in *fig. 6c*, as a function of kR .

The oscillating sphere

According to the foregoing the pulsating sphere may be considered as an idealized form of a loud speaker membrane in a very large baffle board. How must we represent a loud speaker without a baffle board? In such a case it is most essential that the loud speaker membrane moves back and forth as a whole, and that phase differences in the motion in the above described two halves of space occur. If we again idealize the membrane to a sphere we must allow the sphere to oscillate back and forth as a whole, see *fig. 8*. This is called a radiator of the first order.

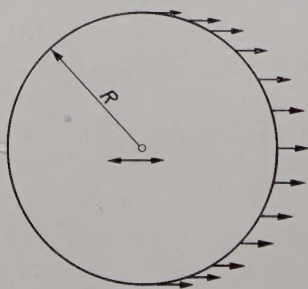


Fig. 8. Oscillating sphere. All points on the surface of the sphere have the same, mutually parallel, velocity. The velocity of the air at any point of the sphere must have a normal component which equals the normal component of the velocity of the sphere at that point.

The difference between the air movement in the case of this oscillating sphere and that in the case of the pulsating sphere lies in the fact that in the latter case there was only a radial flow, while in the former case, in addition to the radial, a tangential flow is also possible. In tangential motion along the sphere the acceleration of the air does not take place by means of a sound wave, but by a different oscillation phenomenon. Let us imagine a purely tangential flow around the fixed sphere between the wall of the sphere and an imaginary sphere somewhat larger in size, *fig. 9*. There will then be a compression of the air at the left and a lowered pressure at the right; the flow is hereby retarded, and then, due to the pressure differences occurring, it continues in the opposite direction. These oscillations of the air are quite analogous to those in an organ pipe closed at both ends having the length πR , and have the following frequency:

$$\omega = \frac{c}{R} \cdot \cdot \cdot \cdot \cdot (18)$$

If we now wish to investigate the reaction of the moving air on the radiator, and as in the case of the pulsating sphere, try to make a mechanical model, we must first consider the radial and the tangential flow each separately.

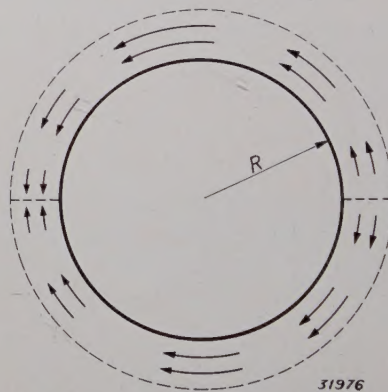


Fig. 9. Tangential motion of the air around the oscillating sphere. The air can carry out an oscillation along the circumference in the same way as in a closed organ pipe of length πR .

For the radial flow we can use the same model as in *fig. 3*. For the radial velocity of every point of the wall of the sphere we must take, however, the component of the velocity of the sphere, calculate in every point the pressure, which would exist on a pulsating sphere with this radial velocity and then find the total force by integration over the whole surface of the sphere. In the model (*fig. 10a*) this is expressed in the fact that we must give the mass M_1 and the resistance W_1 smaller values than in the case of the pulsating sphere, namely:

$$\left. \begin{aligned} M_1 &= \frac{4}{3} \pi R^3 \rho \\ W_1 &= \frac{4}{3} \pi R^2 \rho c \end{aligned} \right\} \dots \dots (19)$$

The tangential flow is represented by a mechanical model which can carry out undamped oscillations, a combination therefore of a spring and a mass, see fig. 10*b*. The relation between the stiffness of the spring S_2 and the mass M_2 is determined by

$$\sqrt{\frac{S_2}{M_2}} = \omega,$$

where ω is given by (18).

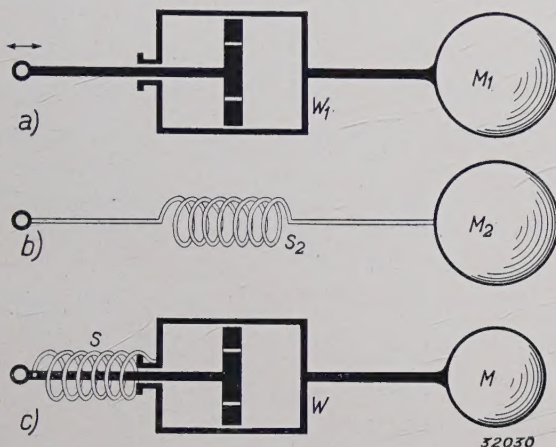


Fig. 10. For the reaction of the air on the oscillating sphere a mechanical model can be used which is composed of two parts.

- a) Model for the radial movement of the air (as in fig. 3);
 b) Model for the tangential movement of the air;
 c) Coupling of models a) and b). Both forces and masses are connected "in parallel".

By combining the two models in fig. 10*a* and *b*, the model in fig. 10*c* is obtained. The fact that the two parts must be coupled in the manner here shown may be explained as follows. The pressure is a scalar quantity, *i.e.* whether it occurs due to compression in radial or tangential direction it will have an accelerating action in both directions. The resistance and the spring must therefore be coupled in such a way that the sum of their forces has an accelerating action on the two masses M_1 and M_2 . The two masses together can, however, be replaced by a smaller mass M : $1/M = 1/M_1 + 1/M_2$, because they must be connected "in parallel". For the expansion of the air is the sum of the expansions in radial and tangential directions. The acceleration of the resultant mass in the model must therefore be made larger with the same force, and therefore the mass must be chosen smaller.

The reaction of the model of fig. 10*c* on the driving centre may again be derived simply from the equations of motion:

$$M \cdot \frac{dv_2}{dt} = K = W v_1 + S \int v_1 dt$$

and

$$v_0 = v_1 + v_2.$$

With sinusoidal motion the following impedance is found:

$$\frac{1}{Z} = \frac{v_0}{K} = \frac{1}{W + j\omega} + \frac{1}{j\omega M} \dots (20)$$

If M_2 is chosen equal to M_1 , so that in the complete model

$$\left. \begin{aligned} M &= \frac{2}{3} \pi R^3 \rho \\ W &= \frac{4}{3} \pi R^2 \rho c \\ S &= \frac{4}{3} \pi R \rho c^2 \end{aligned} \right\} \dots \dots (21)$$

then the reaction of the model on the driving centre is found to be quantitatively the same as that of the air on the oscillating sphere³⁾.

If we now attempt to obtain a clear picture of the behaviour of the radiator from the model, it becomes evident that even with the driving centre fixed, this model will be able to carry out a (damped) oscillation, in which the mass is kept in motion by the spring. When the driving centre moves, the spring will, however, also make itself felt outside the "resonance frequency" by the taking up of energy. This will be appreciable especially at low frequencies, because the energy which the spring takes up is determined by its change in length, while the energy dissipated in the frictional resistance is determined by the velocity. At low frequencies therefore the spring will be able to take up much energy without great dissipation in the resistance, *i.e.* at low frequencies the tangential flow of the air around the oscillating sphere will be most disadvantageous to the sound energy, which is already small at low frequencies. At high frequencies, on the other hand, the spring will introduce no important changes in the behaviour of the model with respect to the one discussed earlier: due to the large forces of inertia only small movements of the mass occur, the spring absorbs little energy in these small movements, and due to the high velocities the greater part of the energy is again dissipated in the resistance, *i.e.* radiated as sound.

For a more accurate insight into the dependence of radiation on the frequency we may again divide

³⁾ This can be derived in a similar way as in the case of the model for the pulsating sphere. For the sake of brevity we omit the derivation at this point.

the impedance (20) into a real and an imaginary part, $Z = Z_r + j Z_i$, as was done above. Again we find that in these expressions, which indicate the acoustic energy given off and the wattless energy stored up in radial and tangential air flow, respectively, the frequency only occurs in the product kR . In *fig. 11* the variation of Z_r and Z_i as a function of kR is drawn.

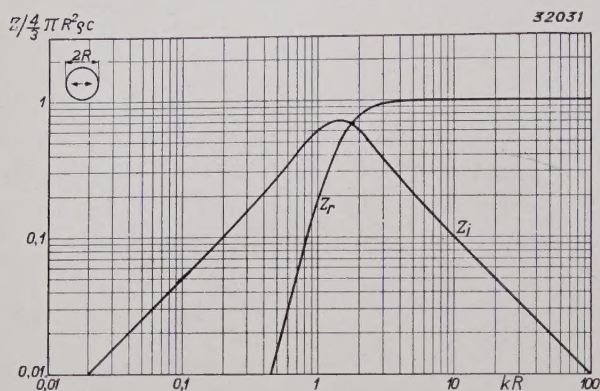


Fig. 11. Real and imaginary impedance of the air set in motion by an oscillating sphere, as a function of kR .

Since for practical purposes one is specially interested in the acoustic energy dissipated, we have in *fig. 12* again given Z_r for the pulsating sphere (loud speaker with baffle board) and for the oscillating sphere (loud speaker without baffle board). The dimensions of the two radiators are so chosen that they both displace the same volume of air by their motion. The oscillating sphere then must have a radius which is $\sqrt{2}$ times that of the pulsating sphere.

From the figure it may be seen in the first place that the acoustic power in the case of the oscillating sphere falls more rapidly toward low frequencies than in the case of the pulsating sphere (namely, proportional to the fourth power of the frequency

instead of the square). Furthermore with the oscillating sphere the radiation as a whole, and especially at high frequencies, is less than with the pulsating sphere. This fact can be explained in the model by the smaller and therefore more easily movable mass, which belongs to the case of the oscillating sphere (the ratio of masses being $\sqrt{2}/3 = 0.47$) and by the spring which again absorbs a certain amount of wattless energy. Transferred to the medium the latter may be expressed by saying that the omission of the baffle board with a loud speaker cone results in a decrease of the acoustic power, due to the fact that a tangential motion of the air between the front and back of the membrane takes up part of the expansion of the compressed air. Quite in general one may say that the radiation is unfavourably affected when the air has the opportunity of moving in other directions than normal to the surface. The pulsating sphere is therefore the most satisfactory form for a sound radiator.

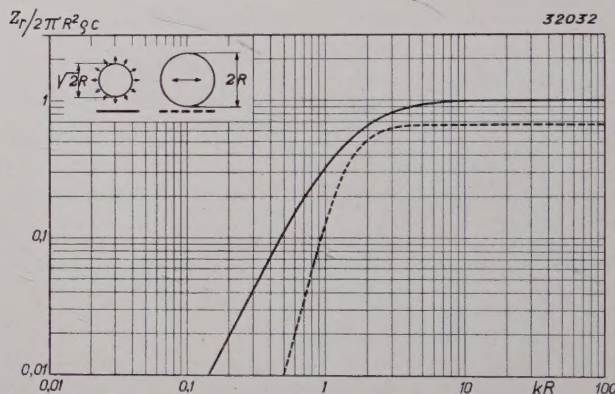


Fig. 12. Comparison of the variation of Z_r , i.e. the acoustic energy dissipated, for a pulsating sphere (continuous) and an oscillating sphere (dotted) of such dimensions that both radiators displace the same amount of air in their motion.

MEASUREMENTS OF POTENTIAL BY MEANS OF THE ELECTROLYTIC TANK

by G. HEPP.

537.213.08

If an electrode system with fixed electrode potentials is immersed in a conducting liquid the variation of potential between the electrodes will remain practically unchanged. The variation of potential in the liquid can now be measured by means of a probe electrode. An apparatus is described in this article with which potential fields can be measured and recorded on this principle with the help of enlarged models. Several applications are discussed and it is explained in particular how it is possible to reconstruct the paths of the electrons in vacuum tubes with this apparatus.

Diagrams have already been reproduced several times in this periodical representing the variation of potential between electrodes, while it has been stated, although very briefly, that these "potentiograms" can be recorded with the help of an electrolytic tank. The purpose of this article is to give a more detailed description of such an apparatus and of the methods of working with it.

In order to determine the variation of potential between two or more electrodes with the electrolytic tank, these electrodes, or proportionately enlarged models of them, are immersed in a conducting liquid. If voltages are then applied to the electrodes any given point in the liquid will take on a definite potential. This potential will depend on the place with regard to the electrodes, but will be independent of the conductivity and the dielectric constant of the liquid. If it is desired to measure this potential a metal wire is introduced into the liquid which is completely insulated except for its point by a glass tube. The potential of this probe electrode is now measured by comparing it with that of the sliding contact of a recording potentiometer. The sliding contact is so adjusted that the difference in voltage disappears, which can be ascertained with a sensitive measuring instrument.

If the electrode system to be investigated has a plane of symmetry, not only with respect to the dimensions of the electrodes but also with respect to their potentials, the potential field is also symmetrical with respect to this plane. Due to the symmetry no current will flow through this plane from the one half of the system to the other. No alteration in the current distribution will be produced therefore if an insulating plane is introduced at the symmetrical cross section. One half of the system may then be omitted without changing the situation of the remaining half.

An intensive use is made of this characteristic in working with the electrolytic tank. If for instance one has an axial symmetrical system, every

plane through the axis is a plane of symmetry. If the electrodes are now placed so that the axis just lies on the liquid surface, the variation of potential on this surface will be the same as that which would be found in a plane through the axis, if the whole model were immersed in the liquid. Now, however, the point of the probe need not be introduced to a certain depth into the liquid (with the result that the insulated connection causes some disturbance of the field), but it is sufficient to measure the potential at the surface of the liquid. The half of the electrodes which would project out of the liquid is now of course omitted. In *fig. 1* two such half electrode systems are given which represent the focusing electrodes of cathode ray tubes.

The action of non-conducting boundary planes of symmetry on the potential field does not, however, always have favourable results. This is only the case when such a plane is a plane of symmetry in the original electrode system. Since the electrolytic tank is limited, each wall and the bottom of the tank must be considered as a plane of symmetry of the potential. Instead, therefore, of measuring the variation of potential of a system isolated in space, one actually measures the potential of a system surrounded by many similar systems due to the repeated reflection at the walls. By suitable arrangement of the electrodes and the greatest possible use of the symmetries present, the disturbance of the field, produced by this effect, can be reduced to fairly small proportions.

Since in measuring the potentials it is only necessary to compare the relative voltage in the liquid with the relative voltage of the potentiometer, the absolute value and the sign of the voltage on the electrodes is unimportant. In the following, therefore, the potential at a point of the liquid means the relative potential, *i.e.* the ratio of the voltage of the probe to the voltage of the electrode with the highest potential, both calculated with respect to an electrode of zero potential.

In order to measure this relative voltage it is

not necessary for the voltage on the electrodes to be constant. An alternating voltage may also be applied, and it is even preferable because the electrolyte is not decomposed at a sufficiently high frequency of the alternating voltage.

Electrolyte and electrodes

For good results it is desirable to make the tank as large as possible. This reduces the errors caused

met satisfactorily by making the surface of the electrodes rough by means of a sand blast, which not only accomplishes an intensive cleaning but also a not inconsiderable enlargement of the surface and thus a decrease of the transition resistance.

The material of which the electrodes and probe are made is copper. Care must of course also be taken that other metals do not come in contact with the water at the same time.



Fig. 1. Enlarged models of electrode systems for cathode ray tubes, constructed for the recording of potential fields by means of the electrolytic tank.

by the finite dimensions of the point of the probe, by the rise of the liquid surface of the electrodes, while at the same time the potentiograms obtained are larger and therefore more accurate.

If the tank has a large capacity, however, it is advisable to use a cheap and sufficiently plentiful liquid in making the electrolytic solution, and therefore not to use distilled water, but water from the mains. It has been found that it is unnecessary to add anything to the mains water, since the conductivity is already more than high enough and a higher conductivity would even be decidedly harmful, because of the transition resistance which occurs on the surface of the electrodes due to impurities or polarization, and which has a greater effect the lower the resistance of the liquid.

Mains water, with its fairly high conductivity, therefore demands a fairly high quality of the electrode surface. This demand can, however, be

Method of measuring

As already stated the potential of the probe is measured by comparing it with that of the sliding contact of a potentiometer from which the relative voltage can easily be read.

Potentiometer

In order to be able to adjust this relative voltage with sufficient accuracy, use is made of a potentiometer connection as indicated in *fig. 2*, which

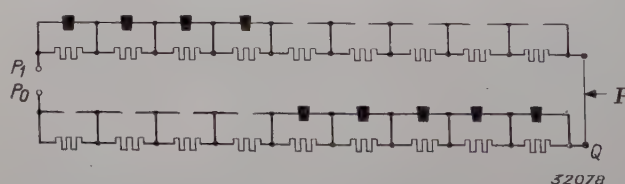


Fig. 2. Potentiometer circuit. The potentiometer consists of 19 fixed resistances, 9 of which are always short circuited by plugs, and a resistance with a sliding contact for fine adjustment.

the two relative voltages, and in moving the contact arm or the probe it is then impossible to see on the phase indicator whether one is increasing or decreasing the input voltage of the amplifier. The rough adjustment is therefore carried out with the voltage indicator. When the two relative voltages have been made approximately equal, the pointer of the phase indicator begins to move.

As has been mentioned the current through the voltage indicator never becomes exactly equal to zero. The indication of this meter is therefore a measure of the phase difference

The AC voltage supply is provided by an electrical tuning fork, combined with a powerful amplifier.

Fig. 4 shows the whole installation. To the extreme left may be seen the electrical tuning fork, to the right of it the power amplifier, in front of the power amplifier the potentiometer and to the right of this instrument the electrolytic tank in which a model of the electrode system of a cathode ray tube has been placed. A pencil is fastened to the frame which holds the probe and which is movable along rails in two mutually perpendicular

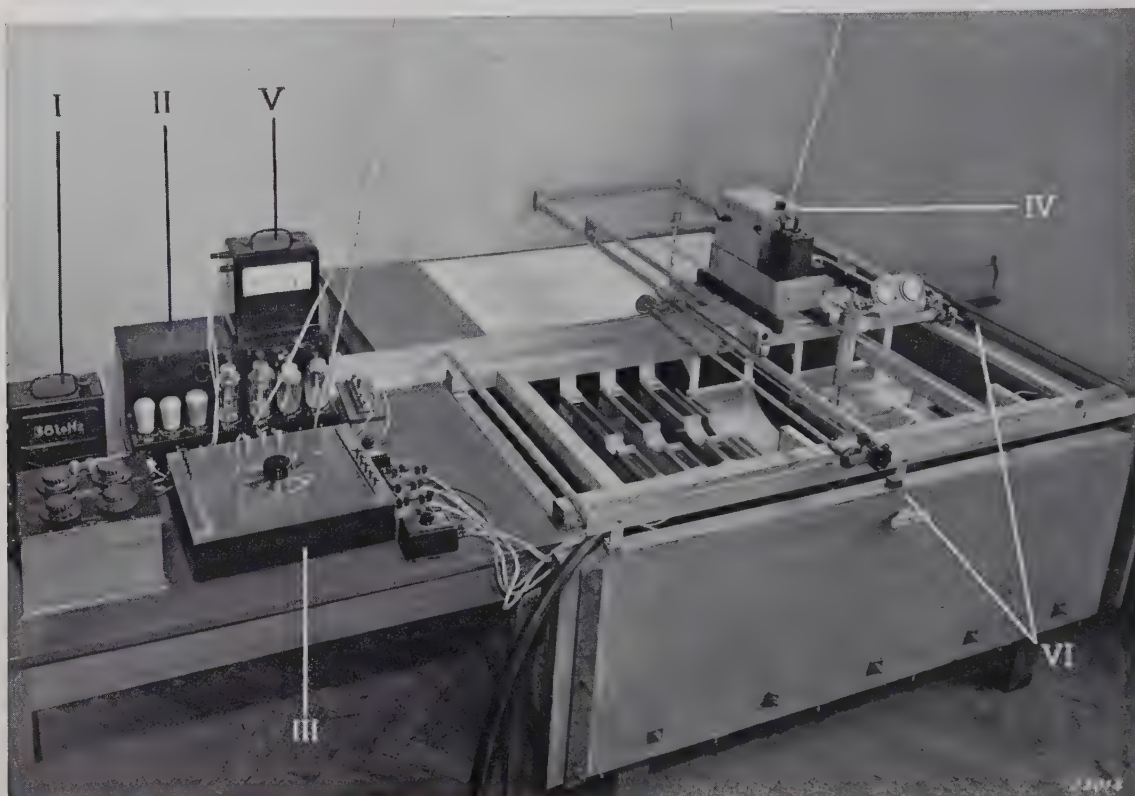


Fig. 4. View of the installation for measuring potentials. In the tank is a model of an electrode system for a cathode ray tube. *I* electrical tuning fork, *II* power amplifier, *III* potentiometer, *IV* measuring amplifier.

occurring, when the phase indicator indicates no current. Thus if the surface of the electrode should become contaminated (by the formation of a film with low conductivity), one is warned by the indication of the voltage meter that the electrode must again be treated with the sand blast before the investigation is continued.

The great sensitivity of the apparatus makes it desirable to take measures to decrease the effect of disturbances. A sharp resonance circuit is therefore introduced into the amplifier and tuned to the frequency of the supply voltage (about 380 c/s). The amplifier is therefore insensitive to the 50 period voltage of the mains or the harmonics thereof, which usually make up the interfering frequency spectrum.

directions. The pencil is held above a sheet of paper upon which the electrodes are drawn. By applying the pencil to the paper the position of the probe with respect to the electrodes can be recorded. On the carrier frame of the probe are also the measuring amplifier and the two meters for voltage and phase indication.

Fig. 5 also gives a more distinct view of these instruments, while the key *T* may also be seen, by means of which the pencil can be pressed against the paper. The most striking detail of this picture is, however, the complicated construction of the probe holder. This construction makes it possible to measure at a given point not only the potential, but also the field strength or the component of the

field in any direction. When the setting plate *Z* at the top of the probe holder is in the position shown in the photograph, the point of the probe can be moved to either side over a distance of 0.5 mm by the turning of a knob *H*. In general this will disturb the voltage equilibrium between probe and potentiometer. The whole probe holder is now turned in such a direction that the turning of the knob does not result in a disturbance of the

electrodes. After the potentiometer has been set at a certain potential, one tries by means of two turnings knobs (*K* in fig. 4) to adjust the probe so that the meters *SI* and *FI* stand at zero. The left hand knob gives a movement to the right and left, while with the right hand knob the carrier frame of the probe can be moved backward and forward. When the correct adjustment has been found the position of the probe can be marked on the paper.

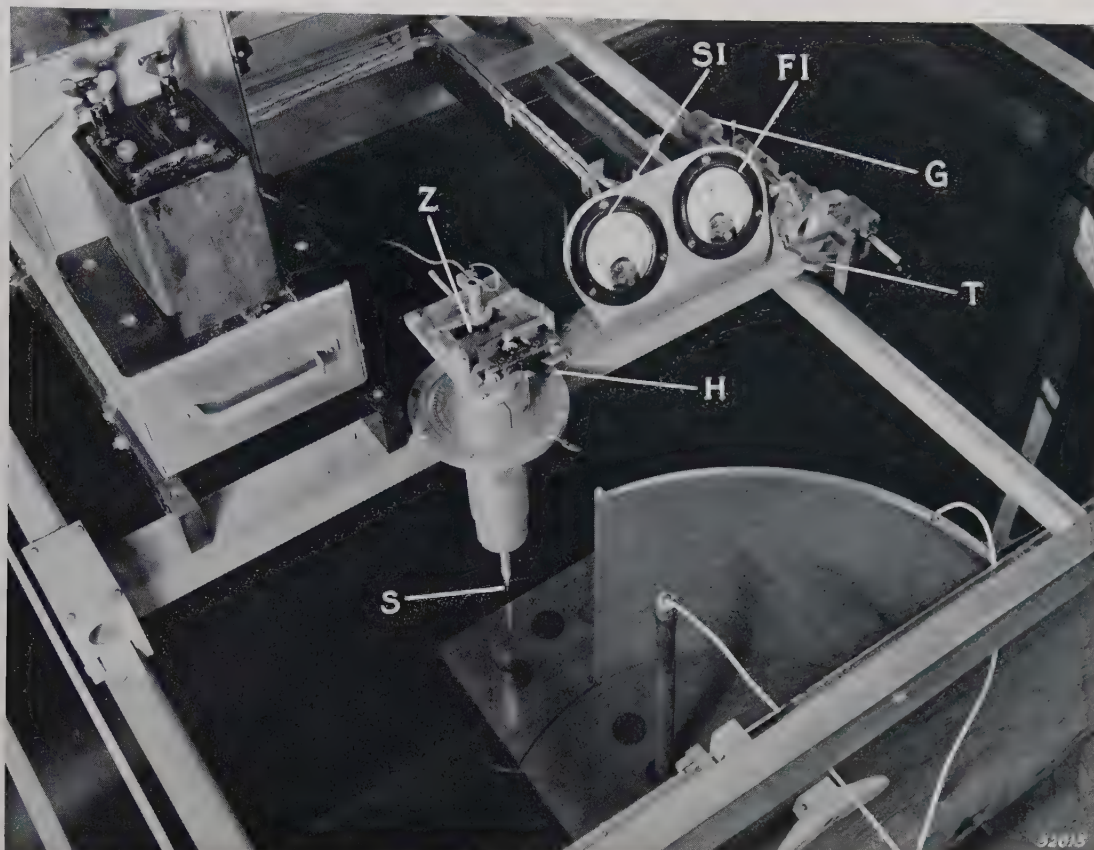


Fig. 5. Detail of the carrier frame above the electrolytic tank. The probe *S* can be moved 0.5 mm to either side by the turning of knob *H*. The direction of the motion is adjustable by turning the probe and can be read off on a scale. To the right of the probe may be seen the meters *SI* and *FI*, and next to them a key *T*, which must be pressed in order to record on a drawing a given position of the probe. If it is desired to draw continuous lines the key *T* must be held pressed, which can be accomplished by reversing a lever with a weight *G*. By moving the setting plate *Z* the amplitude of the lateral motion of the point of the probe can be increased tenfold, or the probe can be locked in its middle position.

equilibrium. The direction of motion of the point of the probe is then perpendicular to the direction of the field and can be read off from a scale, so that the field direction is also known. If the probe holder is now given a quarter turn, a maximum change in the potential is obtained upon turning the knob. From this change the field strength can be calculated.

Recording the potentiograms

Fig. 6 shows how the apparatus is operated in recording the variation of potential between the

In this way a series of points of equal potential can be determined, and these points are afterwards connected by a smooth curve. Other potentials are then chosen and the equipotential lines are constructed point by point.

In some cases the equipotential line can be drawn directly by having one knob motor driven, and turning the other one continuously by hand so that the meters remain at zero. This is of course only possible when the equipotential line has no point of inversion in the direction in which the carrier is moved by the motor. The key *T* can then remain

depressed, which is accomplished by reversing a lever with a weight (G in fig. 5).

In fig. 7 a potentiogram is given which was recorded in this semi-automatic manner. The figure relates to the focusing system of a cathode ray tube. The relative voltage increases from one line to the next by the same amount of 1 per cent, so that the density of the lines is a direct measure of the field strength at that point.

Applications of the electrolytic tank

An important sphere of application of the electrolytic tank and the potentiograms obtained by

tential lines). This line cuts circle U_2 at G . If M is the middle of FG then v_2 has the same direction as OG , while the chord $I-2$ has the same direction as OM .

The correctness of the construction can be demonstrated as follows. For an electron which obtains its velocity exclusively from the electric field, the following is valid:

$$\frac{1}{2} m v_1^2 = e U_1,$$

$$\frac{1}{2} m v_2^2 = e U_2,$$

where e is the charge and m the mass of an electron. Thus if the line OF represents the vector v_1 , then, due to the fact that



Fig. 6. The operation of the apparatus during the recording of potentiograms.

its use lies in the study of the paths of the electrons in the potential field of an electrode system.

If there are two equipotential lines (with the potentials U_1 and U_2) which lie so close together that the field between them may be considered homogeneous, and if point I is known at which an electron cuts the first line, and the direction of the velocity v_1 of the electron at I , it is possible in a simple way to find point 2, where the electron cuts the second equipotential line and the direction of the velocity v_2 of the electron at that point.

The construction is given in fig. 8, and is carried out as follows. In an auxiliary figure two circles U_1 and U_2 are drawn from point O whose radii are equal to $\sqrt{U_1}$ and $\sqrt{U_2}$. In the first circle a radius is drawn in the direction of v_1 , and from the extremity F of this radius a line is drawn in the direction of the gradient (*i.e.* perpendicular to the equipotential lines).

$$\frac{v_2}{v_1} = \frac{U_2}{U_1}$$

the vector v_2 is represented by a radius of the circle u_2 . Furthermore:

$$v_2 = v_1 + at,$$

where a is the mean acceleration of the electron and t the time during which the electron moves between the two equipotential lines. The vector at has the direction of the acceleration vector a and thus the direction of the gradient, and must in the figure be represented by FG , since this vector has the same starting point and direction as at , and the termination of this latter vector must also lie on u_2 .

For the path vector W the following holds:

$$W = v_1 t + \frac{1}{2} a t^2 = (v_1 + \frac{1}{2} a t) \cdot t, \\ (OF + \frac{1}{2} FG) t = OM \cdot t.$$

The direction of the chord $I-2$ is therefore the same as that of the vector OM .

The intersection of the path of the electron with

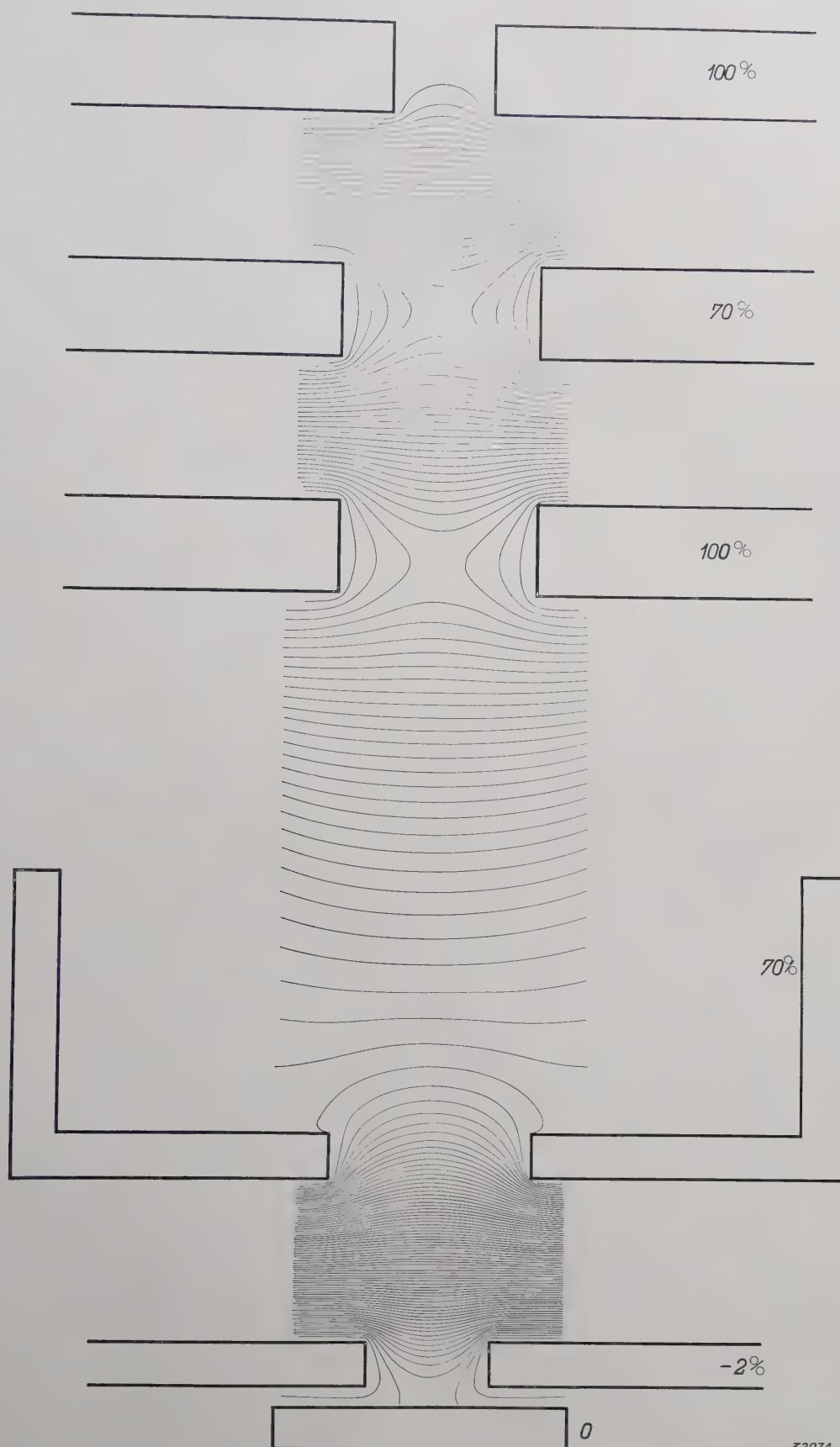


Fig. 7. Equipotential lines in the electrode system of a cathode ray tube. The voltage ratio changes 1% from one line to the next.

the potential line U_3 is constructed in the same way with auxiliary circles whose radii are in the same ratio as $\sqrt{U_2}$ and $\sqrt{U_3}$. If the equipotential lines are chosen so that they form a geometric series (and not an arithmetic one as in fig. 6) it is possible to use the same two auxiliary circles for the construction of all intersections of electron paths and equipotential lines.

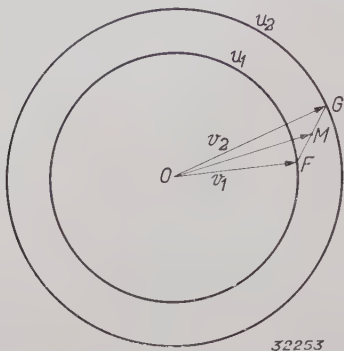


Fig. 8. Construction of electron paths. The radii of circles u_1 and u_2 are proportional to the square roots of the potentials U_1 and U_2 . If v_1 is the velocity in the first equipotential plane, FG the direction of the field, then v_2 is the velocity in the second equipotential plane. The vectorial mean of the velocities v_1 and v_2 has the direction of the path between the two equipotential planes considered. The path can be constructed stepwise in this way.

In this construction it is necessary to know not only the value of the potentials but also the direction of the gradient. The latter could be deduced from the potentiogram if necessary. It is, however, more accurate to measure the gradient in the tank itself as described in the discussion of the probe holder. An improvement is obtained by measuring

the gradient at a point about midway between the two points 1 and 2 instead of at point 1.

Measurements with the potential tank are of course not confined to the sphere of electron optics, a knowledge of the variation of potential is required for the most divergent problems.

The model lying in the tank in fig. 5, relates for example to a gas-filled photocell. This cell actually has a cross section as indicated by the dotted lines in fig. 9, but by making use of the reflection at the wall of the tank it was possible to simplify the model. The purpose of the investigation was to determine the most suitable spot for the anode A in order to satisfy the requirement that the light-sensitive surface should be exposed as little as possible to the bombardment of ions. Since the ions in a gas atmosphere tend to follow the electric lines of force, it can be deduced from the potentiograms where the ions will strike the cathode.

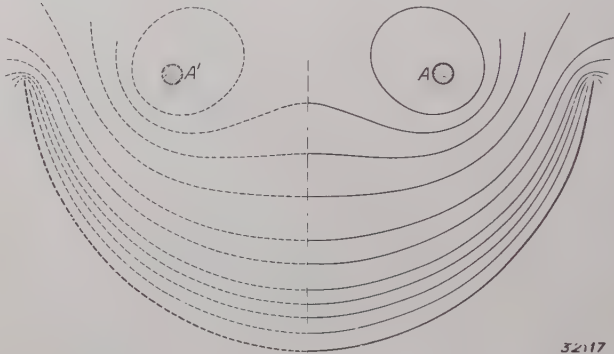


Fig. 9. Cross section of a photocell, the model of which is given in fig. 5, and the course of the equipotential lines in the cell.

RAPID CHEMICAL ANALYSIS WITH THE MERCURY DROPPING ELECTRODE AND AN OSCILLOGRAPH OR MEASURING BRIDGE AS INDICATOR

by J. BOEKE and H. van SUCHTELEN.

535.3 : 621.317.755

It is shown in this article how chemical analysis can be carried out considerably more rapidly with the mercury dropping electrode by the use of an cathode ray oscillograph or a measuring bridge (with the "Philoscop" for instance) as indicator than is possible with the customary recording instruments.

In recent years the electrochemistry of the dropping electrode has developed rapidly, so that at present it offers a many-sided method for the rapid chemical analysis of small quantities of material. It was first used for this purpose by Heyrovsky in the so-called Polarograph, and was later further developed by this students and others, among whom Shikata, Hohn¹⁾, Maas and Kolthoff. There already exist standardized directions for analysis by this method and precise measuring instruments which are in common use. These instruments are however expensive, and also easily damaged because of for instance the use of a galvanometer. Moreover their use involves a time-consuming recording, which, from the nature of the method, cannot be accelerated, as we shall show in this article. With a single slight change this complicated recording instrument can be replaced by a cathode ray oscillograph or a measuring bridge with a „Philoscop” as indicator. The analysis then takes place in less than a minute, while instead of the inevitably elaborate recording, indication and reading take place by means of a calibrated scale.

Electrolysis with a mercury dropping electrode

Most salts are completely dissociated in a dilute aqueous solution into their component, oppositely charged ions. If in a container with such a solution two electrodes are placed, between which an external potential difference of several volts is maintained, the cations (positively charged metal ions) move toward the (negative) cathode where they become discharged by taking up one or more electrons, so that metal atoms are liberated. The anions (negatively charged acid radicals) move toward the positive anode, where they undergo an electrochemical reaction in which they lose one or more electrons.

If such electrolysis is carried out with two mercury electrodes between which is applied an external direct voltage which is made to increase steadily from zero volts, it will be seen that in general an

appreciable electric current does not immediately begin to flow through the dilute solution of the metallic salt. This may be understood upon further consideration of the mechanism of electrolytic analysis.

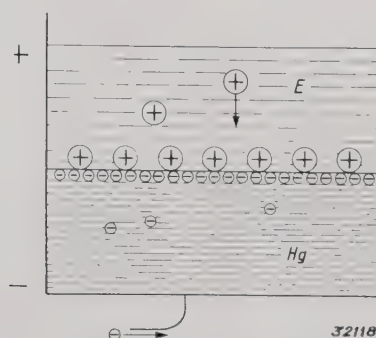


Fig. 1. Electrical double layer of electrons and positive ions at the boundary layer between mercury (*Hg*) and electrolyte (*E*).

At the boundary layer between the solution and the mercury electrode the metal ions from the solution as well as the electrons from the mercury are collected, and together form an electric double layer (*fig. 1*). Only at a sufficiently high voltage does an electron have an appreciable chance of penetrating from the interior of the mercury cathode through the potential barrier of the electrical surface layer and joining a metal ion to form a metal atom. The escaping electrons are then replaced from the source of voltage and in this way a current begins to flow. This current will be proportional to the number of electrons freed, and therefore to the number of available metal ions, *i.e.* to their concentration. If the electric current is plotted as a function of the voltage applied (*fig. 2*) it will be seen that only above a definite voltage V_k does an observable current begin to flow. In the first approximation this current increases linearly with the voltage, *i.e.* as long as the concentration of the metal ions at the cathode increases with the voltage.

If the solution is not too concentrated and if a cathode with a small surface is used, a mercury dropping electrode, for instance, upon further increase of the voltage the state is soon reached

¹⁾ For literature see: H. Hohn, *Chemische Analysen mit dem Polarographen*, Springer, Berlin 1937.

where each metal ion arriving at the cathode is immediately discharged. The electric current is then determined entirely by the speed at which the ions diffuse through the electrolyte. It might be expected

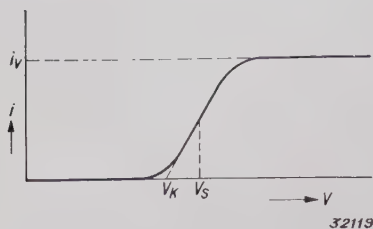


Fig. 2. Current-voltage characteristic for electrolysis with a mercury dropping electrode. V_k is the critical potential at which an appreciable current begins to flow. V_s represents the average value of the potential jump characteristic of a certain kind of ions in the solution. i_v is the saturation value of the current, which is lower the smaller the surface of the electrode and the concentration of the ion in question.

that this velocity of diffusion would increase with the externally applied field, but this is by no means the case, because the influence of the external field is compensated in the electrolyte solution by the large excess of metal ions of a sort which can only be discharged at a higher voltage and which therefore collect around the cathode (Debye-Hückel layer) without being able to reach it. The saturation value of the current does not therefore depend at all upon the externally applied voltage, and is lower, the smaller the density of the ions in the solution and the smaller the surface of the cathode. In the electrolysis with mercury electrodes a capillary from which mercury drops fall regularly is used as cathode and a large mercury pool forms the anode. Not only is the cathode surface then small, but it is moreover formed anew after each drop, so that the boundary layer between mercury and electrolyte cannot become saturated by the metal freed.

Although analogous phenomena of the discharge of ions take place also at the anode, these phenomena do not in any way lead to saturation values of the current flowing, since the mercury pool has a much greater surface than the drop of mercury. The practical possibility of polarographic analysis therefore depends entirely on the use of the dropping electrode.

Furthermore in the case of the dropping electrode hydrogen will not so easily be dissociated from the water which is present in excess during the electrolysis. Depending on the degree of acidity of the solution the hydrogen ions of the double layer are discharged by the electrons only at about 2 volts with the formation of gaseous hydrogen. Practically all other cations, including those of the alkali and alkaline earth metals, have however

then already had the opportunity of being deposited at lower voltages.

The Polarograph of Heyrovsky

Heyrovsky and his school have already been using the current-voltage curve of the electrolysis with the dropping electrode for the chemical analysis of solutions for fifteen years. It is found that, independent of the concentration of a given ion which determines the magnitude of the increase in electric current thereby given, the average potential (V_s in fig. 2) at which this current increase occurs has an easily reproducible value which can be used as indicator for the ion in question. For the successful use of this method of analysis in practical cases extensive tables have been compiled with these average potential jumps V_A , V_B , ... for different ions A , B , ...

The dropping electrode consists of a narrow capillary out of which mercury drops into the solution to be analyzed with a velocity of one drop in 1 to 4 seconds; the drops have a diameter of 0.5 mm at the greatest. The solution can be very dilute, so that extremely small quantities of material can be analyzed in this way. If for example solutions approximately 10^{-5} to 10^{-3} normal are used, the saturation currents are reached already at 10^{-8} to 10^{-5} ampere, since the surface of the drop of mercury only provides a small current cross section.

In fig. 3 the arrangement of the automatic recording Polarograph of Heyrovsky is shown diagrammatically, as well as part of a polarogram obtained by means of this instrument. The voltage applied to the mercury container is tapped off from a resistance cylinder connected with a battery, which, together with the recording drum, rotates with a constant angular velocity. The voltage on the electrolyte container therefore increases pro-

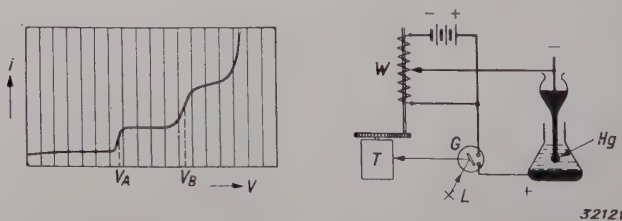


Fig. 3. Diagram showing the principle of the recording of a polarogram. The axis of the recording drum T is coupled with that of the variable resistance W in the form of a spiral which rotates at a constant angular velocity. The voltage on the electrolytic cell increases proportionally with the time, so that the angular coordinate on the recording drum is proportional to the voltage; cf. the accompanying polarogram, in which V_A and V_B represent potential jumps. The electric current flowing through the mercury electrode also passes through the galvanometer G whose mirror throws the light from lamp L on the drum.

portionally with the time and is measured by the angular coordinate on the recording drum. The current gives the galvanometer deviation which is recorded photographically on the rotating drum. In this way the composition can be determined quantitatively of solutions of a concentration at least 10^{-5} normal, and moreover (after calibration) it may be determined quantitatively from the magnitude of the current increase in question.

The photographic recording and subsequent measurement of the polarogram is perhaps no great objection in complex experiments, but for rapid analyses it is too time-consuming. One recording takes from 5 to 15 minutes, after which the polarogram must be developed, fixed and measured. Furthermore the apparatus is expensive and delicate due to the presence of a galvanometer. If an attempt is made to carry out the recording more rapidly by making the drum rotate more quickly and thus by increasing the voltage more rapidly, there is the danger of difficulties due to the intermittent interruption of the current by the falling off of the drop. This difficulty can be met by recording the polarogram with an oscillograph so rapidly that the whole process takes place in the time necessary for one drop to fall. Such a record is however quite inaccurate. Moreover the photography and measuring of the record remains a long operation, so that it is better to replace the recording of the potential jumps by a direct indication.

New methods of measurement

If one allows the direct voltage on the dropping electrode to increase uniformly during a few seconds and superposes upon it an additional small alternating voltage, the potential jumps can be observed directly, as shown in *fig. 4*. In the practically flat part of the current-voltage characteristic such a small alternating voltage does not appreciably change the conduction current, but in a rising part of the characteristic it gives a large fluctuation of the conduction current. In a flat part of the

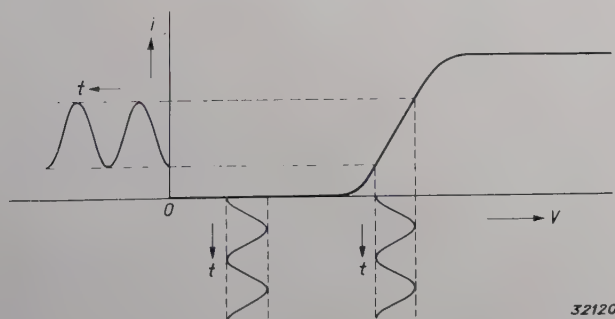


Fig. 4. A small alternating voltage added to the direct voltage has no influence on the current in a flat part of the polarogram. This is not so in a rising part of the curve.

characteristic, however, the alternating voltage gives a fluctuation in the charge on the double layer at the boundary surface, and this entails an action like that of a condenser of about $0.1 \mu\text{F}$. For this reason the alternating voltage leads in the flat parts to a capacitive current which is shifted. At a potential jump alternating voltage and alternating current differ only slightly in phase, and the resistance of the electrolyte cell undergoes a change.

The variation in phase between current and voltage and the variation in resistance and capacity in scanning the direct current characteristic of the mercury dropping electrode with a small alternating voltage may now be used for a direct indication of the potential jumps, so that rapid chemical analysis becomes possible. As indicator an oscillograph or a measuring bridge is used as we shall discuss in the following. The measurement is most easily carried out with the help of an oscillograph, but a somewhat greater accuracy can be attained with the measuring bridge.

The determination of potential jumps with a cathode ray oscillograph

For the determination of potential jumps we used a cathode ray oscillograph, type GM 3152, which was discussed in the previous number of this periodical²⁾. The circuit used is shown in *fig. 5*.

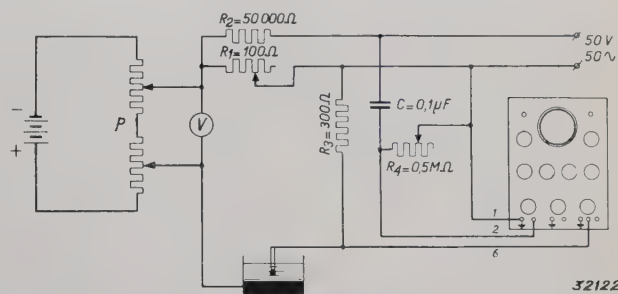


Fig. 5. Circuit for the determination of potential jumps with the cathode ray oscillograph GM 3152 as indicator. *P* is a potentiometer supplying direct voltage which can be read off on the voltmeter *V*. An alternating voltage of 50 c/s is added over the variable resistance *R*₁. By means of the condenser *C* and the variable resistance *R*₄ the alternating voltage, with an adjustable phase shift, is applied to the plates for horizontal deflection of the oscillograph (terminals 1 and 2). The voltage given by the current through the resistance *R*₃ acts on the plates for vertical deflection (terminals 1 and 6).

The electrolytic cell is included in a circuit to which an accurately adjustable direct voltage is applied by the potentiometer *P*. An alternating voltage of 50 cycles, which is taken from the variable resistance *R*₁, is in series with the direct voltage. When *R*₁ is set at its highest value of 100 ohms, the

²⁾ Philips techn. Rev. 4, 198, 1939.

alternating voltage is 0.1 volt R.M.S., which means that the voltage varies continually in the rhythm of 50 c/s over a range of $0.1 \cdot 2\sqrt{2}$ or about 0.3 volt. To the plates for horizontal deflection of the oscillograph (terminals 1 and 2 in fig. 5) the 50 period alternating voltage is applied, so that the horizontal deflection of the cathode ray is proportional to the voltage changes in the current circuit. A voltage acts on R_3 which is proportional to the current through the electrolyte cell, and after amplification it is applied to the plates for vertical deflection of the oscillograph (terminals 1 and 6 in fig. 5).

By means of the potentiometer P the direct voltage on the electrolysis vessel is slowly increased, while a small alternating voltage of 50 c/s is always superposed upon it. As long as the direct voltage has not yet reached the value of the voltage jump, and we are still on the first horizontal part of the characteristic of fig. 4, the changes in current and voltage are still symmetrical with respect to their average values, so that the oscillogram appears symmetrical with respect to its centre (fig. 6).



Fig. 6. Symmetrical oscillograms without an artificial phase shift being introduced between current and voltage.

If part of the region covered by the alternating voltage lies in a rising part of the curve of fig. 4, the oscillogram is no longer symmetrical (fig. 7). This serves as a warning that one is approaching a potential jump. When the direct voltage has reached the average value for the jump, then in that region the relation between current and voltage is again practically linear, so that the



Fig. 7. Unsymmetrical oscillogram such as is obtained at an arbitrary direct voltage in the neighbourhood of a potential jump.

oscillogram is again symmetrical with respect to its centre. As may be seen in fig. 6 these oscillograms are not perfect ellipses but are so deformed that their symmetry or asymmetry is difficult to discover. A linear oscillogram, such as shown in fig. 8,

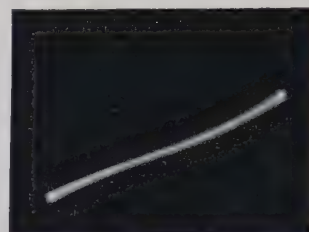


Fig. 8. Current and voltage have been brought into phase with each other so that the oscillogram is approximately a straight line.

gives a much better criterion. In order to obtain such an oscillogram the same phase shift which exists between the alternating current through the cell and the alternating voltage on the cell is caused between the voltage for horizontal deflection and the alternating voltage applied to the cell, by means of the capacity C and the variable resistance R_4 .

When a fairly symmetrical oscillogram has been obtained at a given position of the potentiometer P , the loop form is removed as well as possible by regulating R_4 . Finally the potentiometer must be very critically adjusted for the most symmetrical form of the oscillogram, as illustrated in figs. 9a en b. These figures were recorded at direct voltages which were 0.02 volt higher and lower, respec-

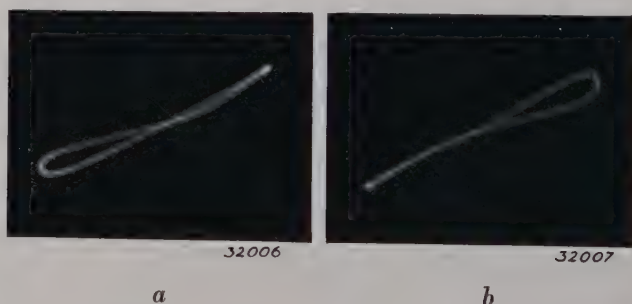


Fig. 9. Oscillograms recorded at direct voltages 0.02 volts higher (a) and lower (b) than those of fig. 8.

tively, than that of fig. 8. These values are small with respect to the intervals between two successive potential jumps for different ions, so that the ions can easily be distinguished from each other.

If the voltage of the potentiometer is adjusted correctly at the potential jump in question, but the alternating voltage used is somewhat high, an approximately symmetrical figure is indeed obtained, but it deviates very much from a straight

line, as may be seen in *fig. 10*. By improving the adjustment of R_1 and giving the oscillograph more



Fig. 10. Symmetrical oscillogram recorded with too high an alternating voltage.

carried out just before the fall of the drop. The volume of the drop increases proportionally with the time t so that its surface increases with $t^{2/3}$ and consequently changes only very slowly shortly before it falls. Since the capacity of the drop is proportional to its surface, the aspect of the oscillogram just before the drop falls is practically constant, which facilitates the observation very much and makes long practice unnecessary.

Fig. 11 is a view of the whole measuring arrangement. The large knob in the centre foreground is for the operation of the potentiometer, behind that is the electrolytic cell with the dropping electrode. On the right stands the cathode ray oscillograph

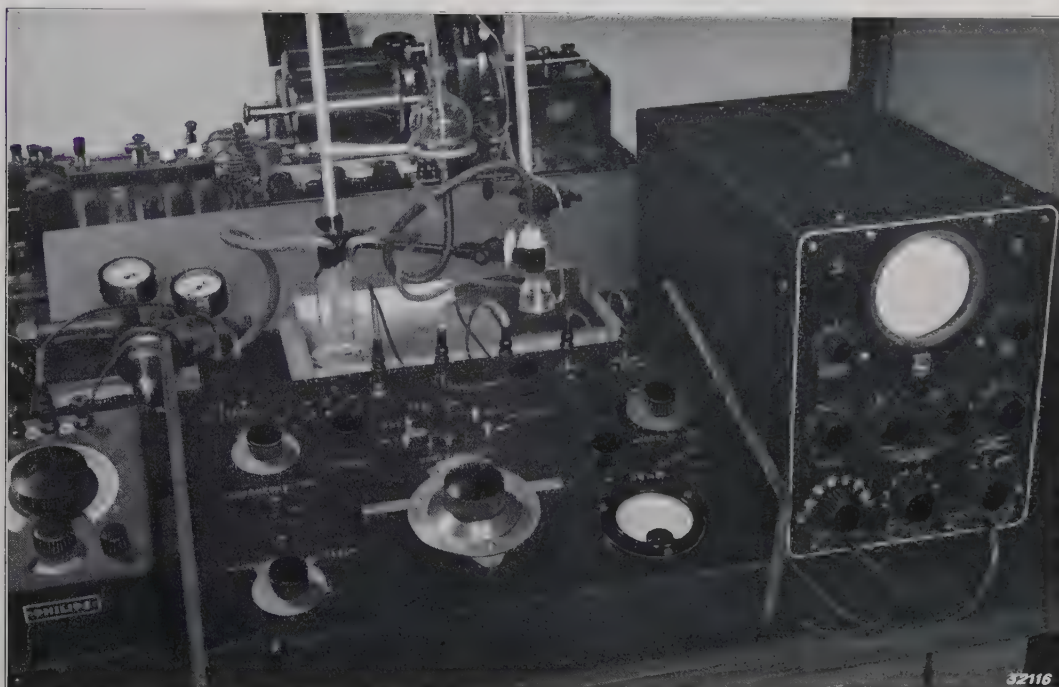


Fig. 11. View of the measuring arrangement. In the centre foreground may be seen the knob of the potentiometer for the setting of the dissociation potential. Behind that is the apparatus with the dropping electrode, while in the background Heyrovsky's Polarograph may be seen. On the right is the cathode ray oscillograph GM 3152, and on the left the "Philoscop" GM 4140, either of which may be used as indicator of the dissociation potentials.

amplification the middle portion of *fig. 10* can be recorded on a larger scale so that the oscillogram finally again takes on the form of *fig. 8*. The position of R_1 is then a measure of the concentration of the ion in question.

In carrying out the measurements account must be taken of the fact that the drop of mercury which forms one electrode grows continually and so also its capacity, so that the aspect of the oscillogram changes. The drop falls once in 1 to 4 seconds, and if the experiment is continued for some time this occurs so absolutely regularly that the observation can without difficulty be consistently

GM 3152, while on the left may be seen the "Philoscop" GM 4140, which, as we shall explain, is also a suitable instrument for indication.

The determination of the potential jumps with the aid of a measuring bridge

At average values of potential jumps the differential resistance of the electrolyte cell shows a minimum, as we mentioned in the foregoing. Since the cell acts mainly as a condenser at a frequency of 50 c/s, the direct voltage at which this minimum occurs can be determined with a bridge arrangement, two branches of which are chiefly

COMBATING RADIO INTERFERENCES

by L. BLOK.

621.396.828

In this article it is shown how radio interferences can be suppressed in the neighbourhood of the source of interference, and how interferences can be prevented from entering the mains. The method is further discussed of combating radio interferences at the receiving set, and the article concludes with several practical examples of the removal of interferences.

Suppression of radio interferences in the neighbourhood of the source of interference

Interference which occur in radio reception due to sudden changes of currents or voltages in electrical apparatus are usually communicated by this apparatus to the radio receiver by way of the light mains. It is therefore of the greatest importance to make it impossible for the source of interference to infect the light main with an interference. How it is possible to prevent an electrical apparatus connected with the light mains from communicating disturbing interference voltage to the mains will be discussed with reference to *fig. 1*¹⁾. The inter-

metrical E_s and the asymmetrical E_a . For the symmetrical component the currents flow at all times in opposite directions in the two circuits 1, 3, 5 and 2, 4, 6, and are equal in value, while it produces no flow of current through earth. For the asymmetrical component the currents always flow in the same direction at all points in the connections, while the earth here functions as return connection. Since the two mains connections usually lie close together and therefore have a large mutual capacity, the symmetrical interference voltage generally does not penetrate far into the mains, and the interferences in radio receiving sets connected with the mains are usually caused by the asymmetrical interference voltage.

A simple method of removing interference, for the case where it is possible to make the provision in front of the input terminals 1 and 2 of the quadrupole V_1 , is represented in *fig. 2a*. If the internal impedance Z_i of the interfering apparatus is not too low compared with E , a satisfactory suppression of the interference can be obtained by connecting a sufficiently large condenser C between the terminals of the source of interference. In some cases of which we shall give an example this condenser must not exceed a defined value.

Fig. 1. Equivalent circuit of a source of interference. The source of interference voltage E with an internal impedance Z_i is situated between the terminals 1 and 2 of the quadrupole V_1 , through which it is connected with the input terminals 3 and 4 of the mains N , the output terminals of which 5 and 6 are connected with the receiving set. $Z_{1a} \dots Z_{6a}$ are earth impedances.

ference voltage which an electrical apparatus can communicate to the light mains is represented in this diagram by a randomly varying EMF E in series with an internal impedance Z_i , both of which are connected through the terminals 1 and 2 by means of a general quadrupole V_1 with the terminals 3 and 4 of the light mains N . The latter again forms a quadrupole between the terminals 3 and 4 and terminals 5 and 6 of the receiving set. Furthermore different points of this circuit are earthed over the different impedances: Z_{1a} , Z_{2a} , Z_{3a} , Z_{4a} , Z_{5a} , Z_{6a} .

In the article cited in footnote¹⁾ a discussion is also given of how the interference E can be divided into two components, namely the sym-

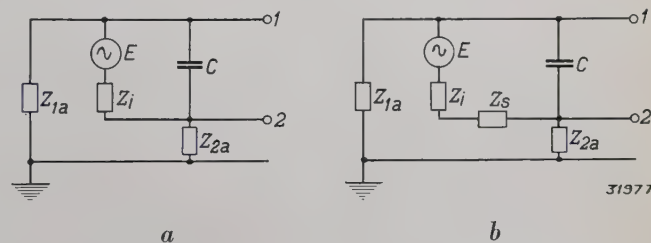


Fig. 2. Suppression of interference is obtained by introducing a capacity C between the terminals 1 and 2 in the circuit of *fig. 1*, when the internal impedance Z_i is not too low (*a*). Otherwise an impedance Z_s must be introduced in series with Z_i (*b*).

In order to attain sufficient suppression of the interference with a condenser which is not too large, the internal impedance Z_i should be artificially increased by connecting an impedance Z_s (a resistance or a high frequency choking coil, for instance) in series with it (*fig. 2b*). By choosing suitable

¹⁾ This equivalent circuit of a source of interference connected with a receiving set by means of the light mains has already been derived in Philips techn. Rev. 3, 235, 1938.

types of resistance or choke Z_s and condenser C , the interference voltage at the terminals 1 and 2 can be made much smaller than the interference voltage E produced by the electrical apparatus. With this connection therefore the whole interference is thus "nipped in the bud".

If a condenser and a choking coil must be used as above for the removal of interference, they can also be connected as indicated in *fig. 3*, and the interference is removed directly at its source. The condenser C is now connected in parallel with the interference voltage E and the internal impedance Z_i . This is only permissible when Z_i is not too small. This connection can be successfully applied when the quadrupole V_1 has an impedance between the terminals 1 and 2 which is small compared with Z_s . It is then as if a double filter were introduced, namely Z_i with C and Z_s with V_1 .

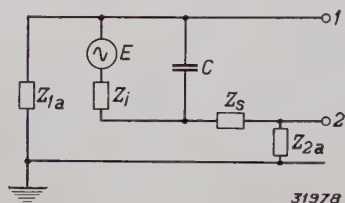


Fig. 3. Behind the interference suppressing condenser C , which together with Z_i forms a filter, another impedance Z_s has been inserted, which, together with the capacity of the quadrupole V_1 , forms a second filter between the terminals 1 and 2. The suppression of interference is thus actually achieved here by a double filter.

For the suppression of interference from alternating current sodium lamps the connection indicated in *fig. 2b* is applied, as has already been mentioned in this periodical²). The element which is composed for this purpose from Z_s and C is a so-called asymmetric interference suppressing filter, since a suitable choking coil or resistance is introduced into only one of the connections, as indicated in the diagram in *fig. 2b*. For the correct functioning of such asymmetrical interference suppressing filters it is necessary that they be introduced close to the source of interference.

Some types of rectifiers can be rendered free of interference in the same way if desired. According to the diagram given in *fig. 4* a high-frequency choking coil is then introduced in each of the anode connections, while beyond the choking coil a condenser C is connected across to the cathode. Alternating and direct current mains are both rendered free of interference in this way. In the application of the scheme of *fig. 4*, however, care must be taken in choosing C , as has been remarked by the dis-

cussion of *fig. 2*. The reignition voltage V_D of a rectifier is considerably higher than its working voltage V_B , so that upon ignition a large EMF

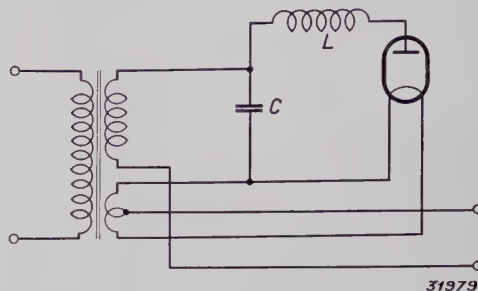


Fig. 4. Suppression of interference from a rectifier obtained by introducing a self-induction L in the anode connection and a condenser C between cathode and anode connection.

$V_D - V_B$ is suddenly released in the circuit between anode and cathode. If the condenser has been chosen too large, it causes large current surges of low frequency through the rectifier valve, which can considerably decrease its life. Especially in rectifiers which can be regulated by means of their grid voltage³) $V_D - V_B$ may be very large, and it is then advisable to avoid a condenser in the connection of *fig. 4*, and to bring about the suppression of the interference in some other way, and not directly behind the rectifier.

Prevention of the penetration of interference voltage into the mains

For practical reasons it is often impossible to reach the place where the interference voltage is generated. In the connections of *fig. 1* it is then only possible to introduce the interference suppressor behind the quadrupole V_1 , for instance between the terminals 3 and 4 which form the output terminals of this quadrupole. If we introduce an

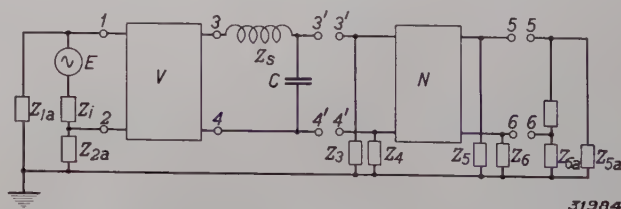


Fig. 5. Suppression of interference is obtained by introducing an element consisting of a condenser C and an impedance Z_s directly behind the quadrupole V , which connects the source of interference with the mains. This must be done when the source of interference E cannot itself be reached for the introduction of an interference suppressing element in the way indicated in *fig. 2*.

asymmetrical interference suppressing filter at that point, as indicated in *fig. 5*, the condenser C between terminals 3' and 4' forms practically a short cir-

²) Philips techn. Rev. 1, 87, 1936.

³) Cf.: Philips techn. Rev. 1, 161, 1936.

cuit for high-frequency voltage. Such voltage does not then occur on the input terminals 3' and 4' of the mains, but over the earth connections Z_{1a} , Z_{2a} , etc. a high-frequency interference voltage may very well reach the input terminals 5 and 6 of the receiving set with the connection 4'4 serving as return connection. In certain cases it is even possible that the interference is somewhat intensified at the receiving set by the introduction of such an asymmetrical interference suppressing filter, since the asymmetry of the mains is changed in such a way that the asymmetrical component of the interference voltage is thereby increased.

If the symmetrical component of the interference voltage plays the main part, which occurs only seldom, removal of interference can of course always be achieved with the connection according to fig. 5. If the earth impedances Z_{1a} and Z_{2a} are not large, it is advisable for the suppression of the asymmetrical component to divide the self-induction of the interference suppressing element over the two connections, as indicated in fig. 6. With such a

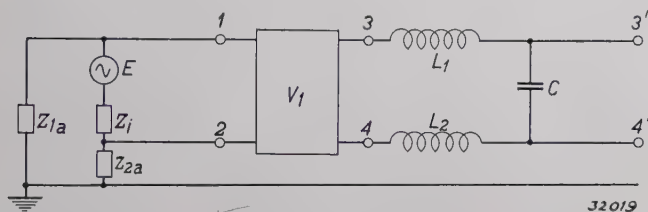


Fig. 6. The interference suppressing element introduced behind the quadrupole V_1 is made symmetrical, so that there is a self-induction (L_1 and L_2) in each of the connections. In this way the asymmetrical interference is satisfactorily suppressed.

connection the impedance of the circuit of the symmetrical interference voltage is not changed, but for the asymmetrical interference voltage, where the earth functions as return connection, the impedance is appreciably increased by the introduction of such a symmetrical interference suppressing filter since 44' now also contains an impedance. The impedances L_1 and L_2 in the two connections need not be equal to each other in this arrangement, but both of them must be sufficiently large. In order to suppress the asymmetrical interference voltage adequately, they must moreover be large with respect to the impedance of the quadrupole V .

In the case of sodium lamps fed through a leakage transformer, suppression of interference according to the scheme of fig. 6 is automatically obtained. As indicated by the broken line in fig. 7, the capacity of the supply cable then functions as condenser C in the scheme of fig. 6, while the leakage field of the leakage transformer plays the part

of the choking coils L_1 and L_2 in that scheme. Since each of the connections of the supply cable possesses in addition an appreciable capacity with respect

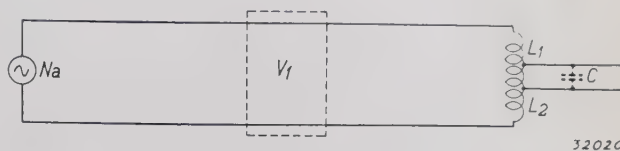


Fig. 7. Upon the use of a leakage transformer the sodium lamp Na is rendered free of interference without special precautions according to the principle of fig. 6, by the leakage reactances L_1 and L_2 and the capacity C of the mains connections.

to the earthed covering of the cable, a suppression of interference is often obtained automatically with the leakage transformer according to a still better scheme, which is given in fig. 8. In this the condenser C is divided into C_1 and C_2 which are in series, while their point of connection is connected with earth. This earth connection naturally possesses an impedance which we have indicated in the figure as Z_{Ca} . Only in the case where this earth impedance Z_{Ca} is small with respect to the impedances Z_3 and Z_4 of the earth connections of the input terminals 3' and 4' of the mains, is it effective, because it then provides that the asymmetrical circuit is connected through itself with earth, so that the high frequency current no longer penetrates into the net with disturbing intensity. The size of Z_{Ca} depends upon the length of the earth connection, which is proportional to its self-induction, and it depends also especially upon the local character of the soil by which the transition resistance is determined.

If the impedance of the quadrupole V_1 as well as Z_3 and Z_4 is not small, it is possible to omit the self-inductions L_1 and L_2 from the scheme of fig. 8, and to obtain a good suppression of interference by introducing only the condensers C_1 and C_2 with their earth connection Z_{Ca} . In such a manner a dynamo or motor with collector can be rendered free of interference, if, as is customary, each of the brushes is connected over a condenser with the earthed housing of the machine.

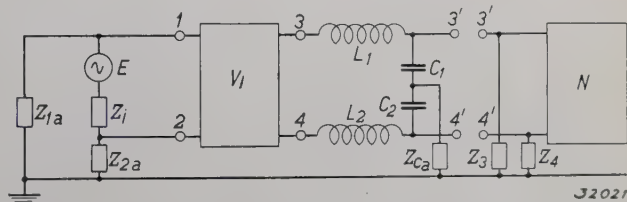


Fig. 8. The interference suppressor is made more symmetrical than in fig. 6, since the condenser is divided into C_1 and C_2 whose point of connection is connected through Z_{Ca} with earth.

In general, by introducing two condensers C_1 and C_2 with their earth connection Z_{Ca} , a satisfactory suppression of interference can be obtained. Two situations may, however, occur which make this impossible; namely when:

- 1) the earth impedance Z_{Ca} cannot be made sufficiently small, or
- 2) the earth impedances Z_3 and Z_4 of the input terminals of the mains are themselves already low and an interference nevertheless occurs.

In the first case one may with much difficulty succeed in diminishing the earth resistance by a factor 2 or 3, for instance, but this is usually insufficient for a satisfactory suppression of interference.

In order to understand the situation in the second case it is necessary to find out how the earth impedances Z_3 and Z_4 are constituted. Although they are given schematically as impedances concentrated in one point of the circuit, they are actually for the most part continuously distributed stray capacities which depend upon the length of the cables which are included in the quadrupole N . The farther the radio receiver is from the source of interference the greater will be the effective stray capacity between the two, so that the earth impedances Z_3 and Z_4 become smaller. This will in general result in the fact that receivers will suffer less from interference the farther they are from the source of interference. The second case can therefore only occur when a very strong source of interference is still found to have a disturbing influence on a far distant receiver. The asymmetrical interference current should then already have sufficient opportunity to flow off to earth over the small earth impedances Z_3 and Z_4 without condensers C_1 and C_2 with their earth connection Z_{Ca} being specially introduced for that purpose, and should therefore no longer be able to penetrate in disturbing intensity into the mains. For this, however, the inter-

ference voltage on the terminals 3 and 4 is found to be too high, nor is the scheme of fig. 8 capable of improving the situation appreciably.

In the two cases here described a connection according to fig. 9 may give the desired result. In this arrangement the condensers C_1 and C_2 form a short circuit for high frequencies between the two mains connections and earth, preceding the self-inductions L_1 and L_2 which serve to prevent the interference current from penetrating into the mains. We now have as it were the symmetrical interference suppressing filter of fig. 8 connected in the opposite way, and this suppression of interference is particularly effective when the internal impedance of the quadrupole V_1 is not too small. In that case one is actually concerned with a double filter: V_1 forms the first filter together with C_1 and C_2 , and L_1 and L_2 together with Z_3 and Z_4 , form the second filter.

Combating radio interferences at the receiving set

In the foregoing we have discussed how precautions can be taken in the more or less immediate neighbourhood of the electrical apparatus in order to prevent its giving rise to interferences in radio reception. We shall now deal with the measures which may be taken in the neighbourhood of the receiving set against radio interferences.

In fig. 10 a diagram is given of the input of a radio receiving set, accompanied by an equivalent circuit⁴⁾. Those interferences which are capable of causing the occurrence of an appreciable interference between the cathode and the grid of the receiving valve, *i.e.* over Z_1 , in the equivalent circuit, will be disturbing for radio reception. We must keep in mind here that in the practical case of a good receiver care is taken that the capacitive coupling C_t between the primary and the secondary winding of the supply transformer is made sufficiently small, so that one need not in general fear that disturbing interference voltages will act across Z_1 by way of the circuit V_a , C_t , Z_1 , C_a , A_2 , A_0 . If this should be the case the impedance of this circuit can be increased by introducing a high-frequency choking coil in series with C_t , *i.e.* in the primary connection of the supply transformer which coil has an impedance which is large with respect to that of C_t and also with respect to the earth impedance Z_{0a} , so that the interference current still flowing through C_t can easily flow off to earth (A_1) and only an extremely small fraction passes through Z_1 and C_a to A_2 .

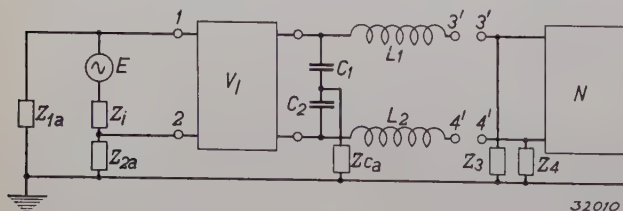


Fig. 9. The interference suppressor of fig. 8 is connected in the opposite way, since the self-inductions L_1 and L_2 are introduced behind the condensers C_1 and C_2 in the mains connections. In this way we have actually again obtained a double filter as in fig. 3. The output impedance of the quadrupole V_1 together with C_1 and C_2 forms the first filter, while the self-inductions L_1 and L_2 , together with the capacity between the input terminals $3'$ and $4'$ of the mains, form the second filter.

⁴⁾ This circuit has already been given in Philips techn. Rev. 3, 240, 1938.

For the communication of interference voltages from the mains to the grid of the receiving valve the capacitive coupling C_k between the supply mains and the leadwire of the aerial A usually, however, plays the most important part. The interference voltage in this case acts on Z_1 by way of the circuit V_a , C_k , Z_1 , Z_{0a} , A_1 , A_0 . By the use of special aerials, the interference current through this circuit may be kept low, but we shall not go into this point in this article. We shall here only discuss what can be achieved by shielding the lead of the aerial along a good part of its length.

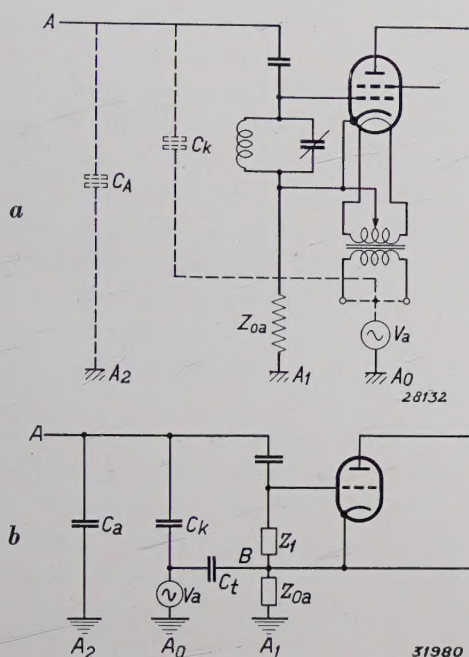


Fig. 10. Circuit of the input of a radio receiving set (a) with the corresponding equivalent circuit (b). The aerial A is loosely coupled with the tuned circuit represented by Z_1 . The aerial lead wire possesses stray capacities C_A toward earth (A_2) and C_k toward the source of interference V_a . The earth point B of the receiving set is connected with earth A_1 over the earth impedance Z_{0a} . The capacitive coupling of the source of interference V_a with the supply side of the receiving set over the supply transformer is represented by C_t .

This shielding is obtained by the use of shielded cable, whose core, which serves as aerial lead, has only a low capacity with respect to the earthed metal covering. The capacity C_0 in fig. 11 is therefore small, so that the intensity of reception is not thereby decreased disturbingly. The earthing of the metal casing is done by connecting it with the earth point B of the receiver, as indicated in fig. 11. As a result the interference voltage V_a can now no longer cause an interference current to penetrate into the receiving set over the aerial input by means of a capacitive coupling (C_k in fig. 10) between supply mains and aerial input lead, because the coupling capacity C_k' in fig. 11 means only an in-

crease of the capacity C_t of the transformer windings.

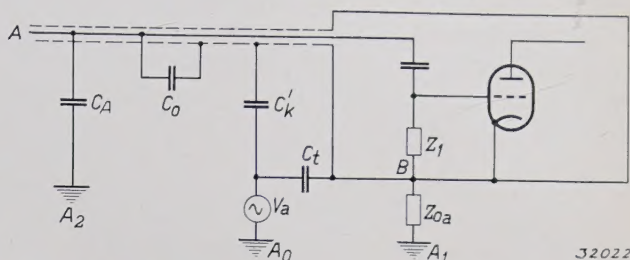


Fig. 11. Interference suppression in the radio set of fig. 10 by means of shielding the aerial (dotted line). This shielding is connected with the earth point B of the receiver which is connected with earth (A_1) via Z_{0a} . The shielding has a capacitive coupling C_0 with the aerial connecting wire and C_k' with the source of interference V_a . The latter can no longer, as in fig. 10, cause an interference to penetrate into the receiving set by way of the aerial connection.

The only circuit over which an interference current can now pass through Z_1 is: V_a , $C_t + C_k'$, Z_1 , C_A , A_2 , A_0 . Just as was noted in the discussion of the circuit over C_t and Z_1 in fig. 10, here also no disturbing interference circuits will flow in the circuit of $C_t + C_k'$ and Z_1 in fig. 11, if only the earth impedance Z_{0a} can be made small enough with respect to the impedance of the capacity $C_t + C_k'$. Practically the interference current is then immediately conducted to earth (A_1) through Z_{0a} . The suppression of interference which can be obtained with shielding is better, the smaller the earth impedance Z_{0a} compared with the impedance over the connection Z_1 , C_A , A_2 .

Several practical examples of the suppression of interference

We shall in conclusion deal with several examples of the way in which suppression of interference can be obtained in practical cases. If the radio interferences are for example due to a three-phase rectifier, whose anodes can easily be reached and do not carry too heavy currents, so that a self-induction can be included in the anode supply line close to each anode, the suppression of interference can be achieved on the principle indicated in figs. 2b and 4 in the direct neighbourhood of the source of interference. In the case of the circuit given in fig. 12 the anode supply lines are connected with the zero point of the cathode through the condensers C_1 , C_2 , C_3 , directly outside of the self-inductions L_1 , L_2 , L_3 , so that the interference is then indeed "nipped in the bud" and has no chance of penetrating the mains. The condensers in this case are expressly connected with the cathode and not with earth, because in this way the interference current has not the slightest chance of penetrating

into the direct current mains. If C_1 , C_2 , C_3 were earthed, the interference current circuit would have to be completed over the divided capacity between the + and - connections. If it is desired to earth C_1 , C_2 , C_3 , then the + and - connections must be short circuited for high frequency with a condenser close to the rectifier.

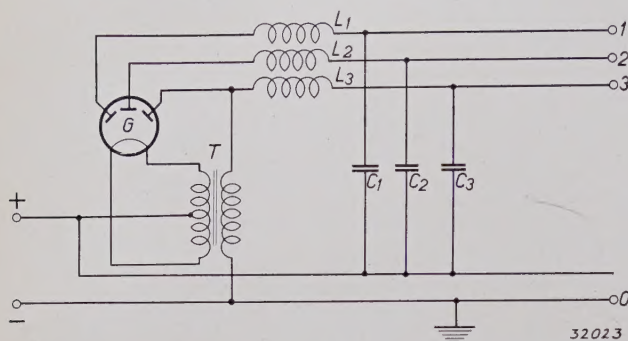


Fig. 12. Suppression of interference from a three-phase rectifier G connected directly with the mains (1, 2, 3) by the self-inductions L_1 , L_2 , L_3 and the condensers C_1 , C_2 , C_3 according to the principle indicated in fig. 2b and 4.

If one is concerned with a three-phase rectifier for high power, whose anodes are in general not connected directly with the mains, but are fed *via* a transformer, the anode currents are too large, and the anodes are generally too difficult to reach to make it possible to introduce self-inductions in the supply lines close to the anodes. Such a case may for instance occur in the neighbourhood of a cinema theatre in which a rectifier fed by the three-phase mains serves as source of energy for the carbon arc in the projector. In one such case where by means of measurements with a portable receiver it could be ascertained that in the neighbourhood of the cinema the light mains were infected with a disturbing radio interference, we were able to bring about an effective suppression of the interference by introducing self-inductions L_1 , L_2 , L_3 in the supply of the transformer and connecting these lines immediately outside of the self-inductions with earth over condensers C_1 , C_2 , C_3 as indicated in fig. 13. Since in this case the interference was propagated by means of the mains,

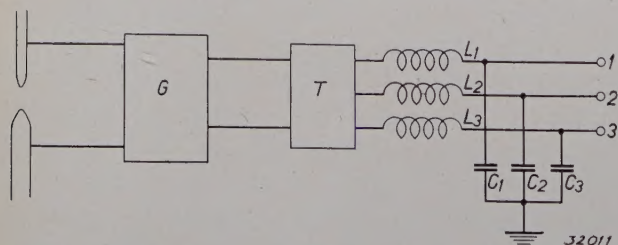


Fig. 13. Suppression of the interference from a rectifier installation G with a transformer T according to the arrangement given in fig. 8.

at some distance the asymmetrical interference voltage was the only disturbing factor, and the circuit of the asymmetrical interference voltage is closed by this arrangement directly behind the transformer, as has already been explained with reference to fig. 8.

In the case under consideration self-inductions of 0.2 mH were used which were wound as sole-noids of one layer in thickness around a hollow core in order to prevent the windings from possessing too high a capacity with respect to each other. If the capacity of the coil itself is too great it would be possible that the self-induction of the coil would be short circuited for the high frequencies of the range which one wishes to render free of interference. The resonance frequency of the coil should be higher than the frequencies to be freed of interference. If we may neglect further impedances, the series impedance in the supply line, for interference waves of 300 m, i.e. 1 Mc/s is $\omega L = 2\pi \cdot 10^6 \cdot 0.2 \cdot 10^{-3} = 1256 \Omega$. Since condensers of 0.1 μ F were used, the impedance of the shunt on the supply line amounts to:

$$\frac{1}{\omega C} = \frac{10^{-6}}{2\pi \cdot 10^7} = \frac{1}{0.628} \Omega.$$

The division of voltage obtained by this arrangement reduces the interference voltage which penetrates into the mains, therefore, by a factor equal to $0.628 \cdot 1256 \approx 800$, which constitutes a satisfactory suppression of the interference. As a result of the unavoidable earth impedance, in practical cases the suppression factor will be smaller.

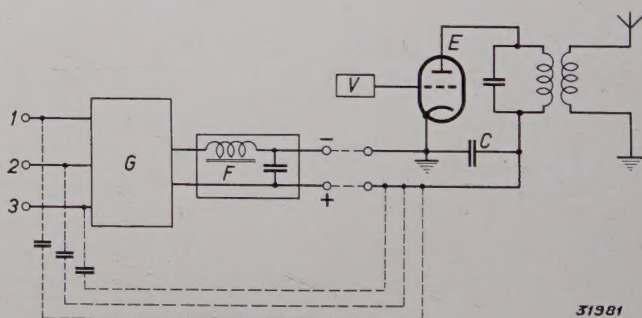


Fig. 14. Interference suppression in a radio transmitter. The six-phase rectifier G connected with the mains (1, 2, 3) supplies by means of the smoothing filter F the anode voltage for the final stage of the transmitter. The pre-stage V supplies the grid voltage for the end valve E . The connections of the supply mains are capacitatively coupled with the feed lines for the final stage, and along this connection intermediate and high-frequency interferences from the rectifier could enter the final stage. This is prevented by short circuiting the feed line for high frequency close to the final stage with a condenser C .

An unusual case of radio interference was encountered in the case of a broadcasting transmitter (fig. 14). The final stage was fed with a sixphase rectifier G for a voltage of 20 kV and a power of

60 kW, which was provided with six gas-filled rectifier valves. The supply is from the three-phase mains of 380 volts and 50 cycles. Per second therefore each valve carries 50 current impulses, so that the total number of current impulses is 300 per sec. The interference spectrum given by the rectifier has a fundamental frequency of 50 c/s, since the six rectifier valves are not exactly alike and it continues up to several hundred thousand c/s. By the smoothing filter F the low-frequency part of the interference spectrum is indeed cut off, but the intermediate and high-frequency part penetrates through the transformer of the rectifier installation into the supply main. The mains cables are capacitatively coupled (shown by dotted line in fig. 14) with the supply lines of the final stage, and therefore generate interference voltage between cathode and anode of the final valve E . In this way the part of the interference spectrum which is not of low frequency enters the final stage where it is modulated on the carrier wave and thus it is transmitted by the aerial.

If we now assume that the interference spectrum extends over a frequency range from 50 to 500 kc/s (fig. 15), after modulation on a carrier wave of 1000 kc/s (wave length 300 m) two side bands occur: 500-950 kc/s (600-316 m) and 1050-1500 kc/s (286-200 m). Since the interference voltages are low, the voltage generated in the aerial by the normal side bands will be much greater than the voltage in the side bands generated by the inter-

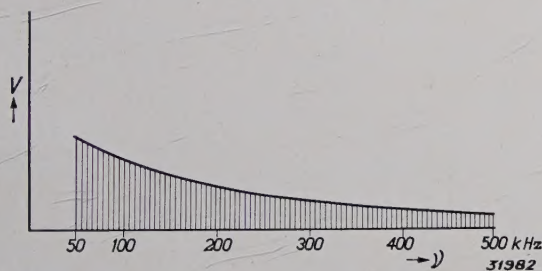


Fig. 15. Interference spectrum of the rectifier of fig. 14. V interference voltage, ν frequency.

ference, as is indicated in fig. 16. At a great distance from the transmitter, therefore, this interference is not observable. If one listens to the trans-

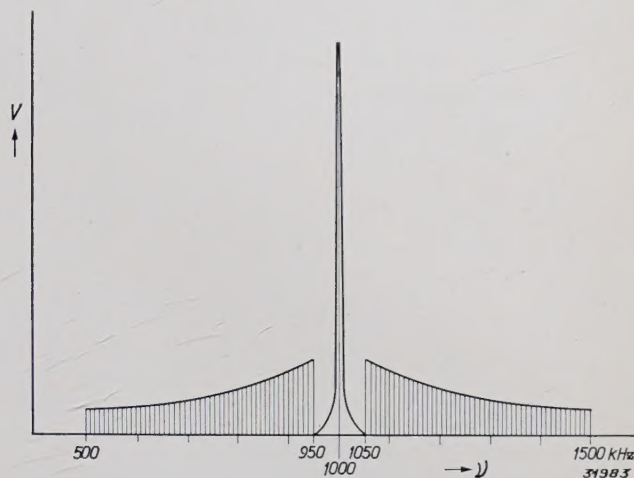


Fig. 16. The voltage V in the aerial as a function of the frequency ν . The carrier wave is at 1000 kc/s; the audible side bands occupy the range 1000 ± 4.5 kc/s, so that the side bands generated by the interference voltages (500-950 and 1050-1500 kc/s) fall outside of this range.

mitter in its immediate neighbourhood, one will again fail to notice the interference, because the normal band width to which a receiver is tuned is about 9 kc/s and practically no interference occurs in the frequency range of 1000 ± 4.5 kc/s. If, however, the receiver is tuned to the frequency ranges 500-950 kc/s or 1050-1500 kc/s, the modulated interference band is then received. Since it contains 6×50 wave trains per sec, this modulation will be heard in the loud speaker as a rattle. The radio reception of stations with carrier waves in the above-mentioned frequency ranges will then be seriously affected.

In this case a satisfactory suppression of interference is achieved by short circuiting the supply lines of the final stage for high frequency close to the transmitting valve by means of a condenser C as indicated in fig. 14.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

1391: J. H. Gisolf: The absorption spectrum of luminescent zinc sulphide and zinc-cadmium sulphide in connection with some optical, electrical and chemical properties. (*Physica* 6, 84-96, Jan. 1939).

The absorption spectra of zinc sulphide and zinc-cadmium sulphide, which are activated with copper, silver and manganese, are very similar; the absorption increases at shorter wave lengths, and at a certain wave length suddenly takes on a very large value. This wave length in the case of zinc sulphide does not depend upon the crystal structure, nor to any large degree on the content of copper and silver. It is the absorption edge of the main component. The sudden great increase in the case of zinc sulphide lies at $3\,350\text{ \AA}$. With zinc-cadmium sulphide the limit is shifted approximately proportional to the content of cadmium toward longer wave lengths. With zinc-manganese sulphides no simple type of behaviour could be determined. It may be observed with zinc sulphide that the fundamental absorption causes a luminescence characteristic of the activator. The limit of absorption is found to indicate a sharp boundary between a region with luminescence times much shorter than 1 sec and that with times of seconds or even minutes. This is easily explained if the process of phosphorescence may be conceived as due to a bimolecular reaction. Due to the great absorption a high density of free electrons occurs, and the intensity therefore decreases rapidly. The limit of photoelectrical conductivity at the short wave end corresponds exactly to the limit of crystal absorption at the long wave end. This latter is also the long wave limit of the photochemical blackening of mixed crystals of zinc sulphide and zinc-cadmium sulphide when irradiated in the presence of water vapour. In conclusion an explanation of crystal absorption is also given.

1392: J. van Slooten: The stability of a triode oscillator with grid-condenser and leak (*Wirel. Eng.* 16, 16-19, Jan. 1939).

Especially at short waves and with strong back-coupling, triode oscillators with grid-condenser and leak may exhibit a relaxation phenomenon in which the oscillation is interrupted periodically. The phenomenon must be regarded as a lack of stability of the normal oscillation state. The stability is investigated by means of the method of

small oscillations, namely by examining the behaviour of slight fluctuations of the amplitude about its stationary value. A condition for stability is found in this way.

1393: J. van Niekerk and Maria S. C. Bliëk: On the vitamine-D content of cow's colostrum (*Act. brev. Neerl.* 9, 25-26, Jan. 1939).

English investigators have found the vitamine-D content of the milk of a cow the first day after calving (colostrum) to be about three times the value of that of ordinary milk. During the following days the vitamine-D content decreases, and after five days it is equal to that of ordinary milk. The authors have determined with the help of young rachitic rats, that the antirachitic action of the milk of three Friesian cows the first day after calving is six to ten times as great, expressed in international units, as that of ordinary milk.

1394: N. F. Moerman† und H. H. Kraak†: Das Fluoreszenschema der Uranylsalze (*Rec. trav. chim. P. B.* 58, 34-38, Jan. 1939).

The absorption spectrum of uranyl compounds at -180°C has one band in common with the emission spectrum. At room temperature, however, a band is found to be added to the absorption spectrum at the red end, which band corresponds in wave length to the most important of the emission spectrum, while at the violet end of the emission spectrum a band is also added which has the same wave length as the most important absorption band. By means of the potential curve for the uranyl ion as a function of the distance between the uranium and oxygen atoms this behaviour may be explained. At -180°C absorption takes place only from the ground state, while at higher temperatures higher states also begin to play a part. Temperature equilibrium is reached within 10^{-6} sec.

1395: W. J. Oosterkamp: Problems in the construction of technical X-ray tubes (*Dissertation, Delft* 1939).

In this dissertation the requirements are examined which must be satisfied by X-ray tubes if they are to be suitable for: medical photography, medical fluoroscopy, medical therapy, macroscopic examination of materials, or the investigation of crystal structures. Furthermore the permissible thermal loading is investigated for short or continuous loading, and finally several problems are dealt with which occur in working with high tension.